IBA TECHNICAL REVIEW

11

Satellites for Broadcasting

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INDEPENDENT BROADCASTING AUTHORITY

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Technical Editor: Pat Hawker, IBA Engineering Information Service

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IBA INDEPENDENT BROADCASTING AUTHORITY
70 Brompton Road London SW3 1EY *Tel: 01-584 7011 Telex: 24345*

Introduction

by Baron Sewter
Assistant Director of Engineering (Network & Development)
Independent Broadcasting Authority

Although it is only 20 years since the first artificial Earth-satellites were launched, their impact on international telecommunications has been immense. From the first broadcast of a Presidential Christmas message from a tape-recorder carried on the 1958 'Score', they have progressed to the world-wide high-capacity Intelsat multi-satellite system which links together the television services of all continents. Today, in North America and the USSR, 'domestic' satellite systems are providing dedicated distribution links for television and sound radio. The Indian SITE studies of 1975–76 have shown that community broadcasting from satellites is a feasible and attractive system for emerging countries. Few can now doubt that it would be possible to implement direct broadcasting from satellites on the super-high frequencies.

What has been the British contribution to this enormously important new technology? It was West Country-born Arthur C Clarke who, in 1945, first postulated the use of the unique properties of the synchronous geostationary orbit as an ideal place for microwave relay stations in the sky. Less praiseworthy is the fact that it was subsequently left to Dr Harold Rosen and his colleagues at Hughes Aircraft to pioneer synchronous communications satellites in the face of many doubts on the part of European telecommunications authorities.

The UK, however, has subsequently been among the leaders in developing satellite technology for civil and defence communications. Will we have an equally important role to play in satellite broadcasting?

Geography and history are perhaps against us. With a well-developed uhf network of terrestrial transmitters and with no immediately pressing demand for the additional programme channels, we might be excused were we to sit back and rest on our laurels. It could be argued that satellite broadcasting is for the large, developing nations rather than for a small island nation with its 99 per cent terrestrial coverage.

Satellites, although attractive, are vulnerable: vulnerable to the all too critical launch; vulnerable to unintentional or intentional jamming by maladjusted or malevolent earth stations; vulnerable to the techniques that undoubtedly already exist for seeking out and destroying or damaging satellites in orbit. Again, it can be argued that a satellite broadcasting station, in times of emergency, might be 'captured' by a powerful earth station of an enemy and used for the broadcasting of propaganda. It is also questionable whether countries will be prepared to base their entire broadcasting systems on technology of which major elements, including the launching of the satellites into synchronous orbit, remain outside their own control.

Already it is international agreement, rather than solar power technology, that is likely to limit the maximum power flux density within the space coverage areas. Direct broadcasting of conventional amplitude-modulated television signals on 12 GHz would require transmitter peak powers of the order of 75 kW for serving domestic receivers, or about 10 kW for serving community installations. By exchanging bandwidth for transmitter power (for example, by using frequency modulation) the spacecraft transmitter power can be reduced to less than 1 kW for domestic reception or about 100 watts for community installations. A power of 100 watts has already been exceeded at 12 GHz in the Canadian–American 'Hermes' experiments.

Again, relatively few doubts apply to the use of satellites for television distribution; and there are likely to be rapid developments of such a system for Eurovision during the next decade.

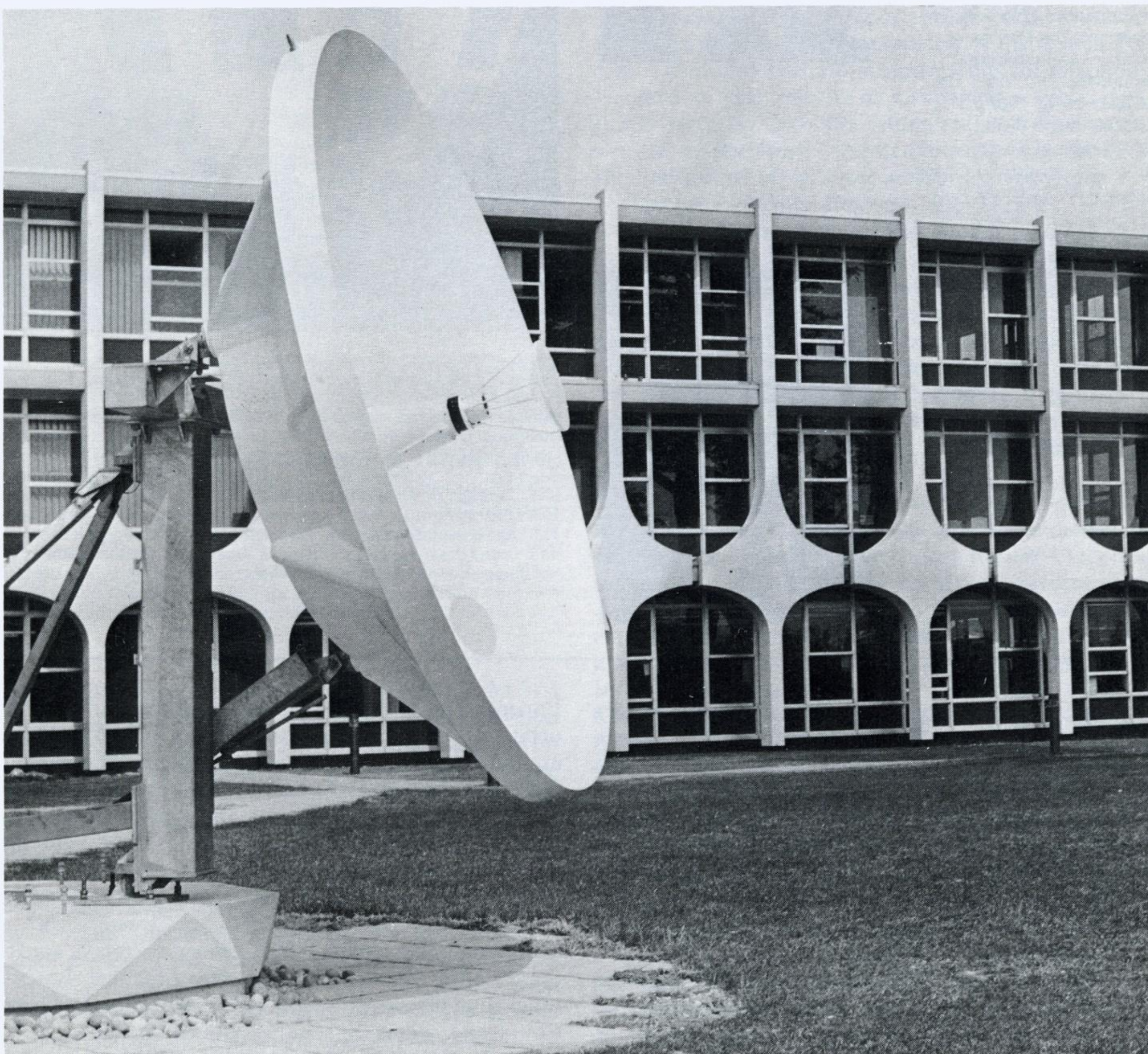
Within the IBA very full support is being given to the experimental work of the European Space Agency, the British Post Office and the European Broadcasting Union. By using beacon signals from the Italian satellite SIRIO, it proved possible to begin in November 1977 the detailed study of 12 GHz radio propagation, that would otherwise have been delayed when the

Thor-Delta launch vehicle for the European Orbital Test Satellite (OTS) failed in September 1977. These studies are being carried out using the special satellite receiving terminal built at the IBA's Engineering Centre during the summer of 1977 at a cost of some £75 000.

The IBA is creating a body of knowledge and expertise that could be deployed on other aspects of space broadcasting as need arises, nationally and internationally.

Some of the many facets of IBA and ITN experience in the field of space in the service of broadcasting are brought together in this issue of the *IBA Technical Review*, together with reference material of use to those working in this exciting area of broadcasting. We are not unmindful of the fact that direct-broadcasting from space has yet to prove that it has a real role to play in the workaday world of broadcasting. The economic and technological considerations are equally important.

The IBA's Earth Station at Crawley Court



A L WITHAM, OBE, MA, C Eng, FIEE, after graduating from Cambridge University, joined the BBC in 1947. In 1955 he joined the Lines Section of the IBA (then ITA) and became the first Head of Planning and Propagation when that department was set up in 1967 to undertake the planning of the uhf network, subsequently being appointed Chief Engineer (Network) in 1973. In 1978 he was appointed Assistant Director of Engineering (Policy). He represents the IBA on a number of international committees and was a UK delegate at the World Administrative Radio Conference on Space Broadcasting, held at Geneva, January–February 1977.

PAT HAWKER.
A biographical note appears on page 27.

Development of Communication and Broadcasting Satellites

by Alfred Witham and Pat Hawker

Synopsis
The first major impact of artificial earth satellites on television broadcasting followed the launching of Telstar in July 1962 and the first 'live' relays of television across the Atlantic Ocean. There soon followed the higher-altitude Relay satellites and then the first 'Syncom' series of communications satellites to be put into geostationary orbit. By 1965 the technology had advanced sufficiently to allow opening of the first operational service via Early Bird (Intelsat I). The next decade saw, besides a rapid increase in satellite capacity for Intelsat, the first uses of 'domestic' satellites for television distribution by the USSR and the Canadian 'Anik' satellites. Direct broadcasting from uhf satellites has been explored in the Indian SITE project and from shf satellites such as Hermes and the current Japanese BSE experiments.

Some account is also given of the European Orbital Test Satellite.

Artificial earth satellites were first successfully launched into orbit twenty years ago and made their first public impact on television broadcasting with the launching of Telstar I into a low-altitude elliptical orbit on 10th July 1962, carrying an 'active' transposer. Television pictures had previously been 'bounced' from passive satellite 'Echo I' which took the form of a metallised plastic sphere of 30 m diameter, but which unfortunately soon became deformed from puncturing of the aluminium-mylar skin.

Although Telstar I, developed by Bell Telephone Laboratories, had a comparatively short operational life, it was used for the exchange of a large number of television programmes between North America and Europe. The period of mutual visibility varied from orbit to orbit, limiting the length of programme exchanges and, of course, resulting often in the satellite not being available when most required for news and sports coverage. To increase the period of mutual visibility the British earth station was sited near the Atlantic coast at Goonhilly Downs, Cornwall and had to be capable of 'tracking' the satellite in its low orbit.

However, Telstar I provided broadcasters with a completely new facility—'live' television relays across the Atlantic. Previously, the only practical system, other than physical transport of tape or film, had been slow-scan systems for sending short news items via the transatlantic telephone cables and requiring as much

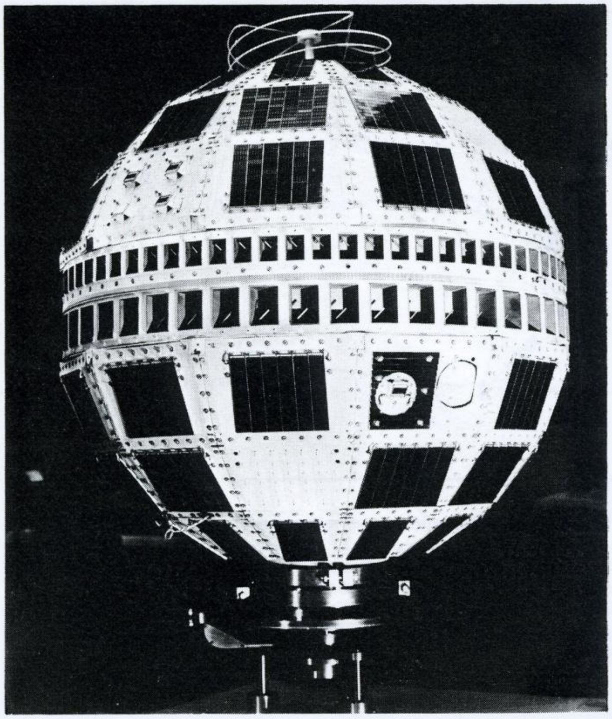


Fig. 1. The Telstar satellite launched in July 1962 made possible the first 'live' television relays between North America and Europe, although its medium-altitude orbit limited programme exchanges to about 20 minutes only and then only at certain times. The satellite, developed by the Bell System (AT&T), provided a complete microwave repeater station, accepting signals on 6·39 GHz and re-transmitting them on 4·17 GHz. It had capacity for some 60 telephone circuits or a single band-limited television channel. The 3600 solar cells mounted in surface facets (sapphire covered) provided the power for the transponder. Telstar contained some 1024 transistors, 1301 diodes and a single travelling-wave-tube. The helical aerial at the top of the satellite transmitted a beacon signal for tracking and telemetry; around the middle of the satellite were two broadband aerials for the transponder.

as 20 minutes transmission time. In 1962–63 the first 'Relay' satellites developed by the Radio Corporation of America (RCA) were launched into a higher orbit 819 miles (perigee) and 4612 miles (apogee). These provided longer periods of mutual 'visibility' but their availability, although predictable, was still often inconvenient.

The Geostationary Satellite

By 1963 an alternative approach—the geostationary satellite—was being actively promoted by Hughes Aircraft, although the idea had originally been suggested as early as October 1945 by the British engineer/science-fiction writer Arthur C Clarke in *Wireless World*. He noted that, if artificial space satellites ever became a reality, there was a unique orbit at a height of 36 000 km (22 300 miles) above the equator where a satellite would appear to remain stationary by reason of its synchronism with the rotation of the earth. He therefore postulated that a world-wide system of telecommunications could be designed using only three satellites carrying microwave repeaters—though it is interesting that current concepts of the reliability of such equipment did not allow him to contemplate 'unattended' operation, and he imagined the satellites as being large manned space stations.

In the early sixties, the geostationary orbit found few supporters. For example, engineers of the British Post Office favoured medium-altitude orbits for telephony, because of the effects of propagation time delay (approximately 250–300 milliseconds on each earth–satellite–earth path), an effect made more significant by the limitations of echo suppressors at that time.

However, during 1963–64, the Hughes Aircraft Company, whose engineering team included such synchronous orbit enthusiasts as Dr Harold Rosen, with the support of the National Aeronautics and Space Administration (NASA) and the US Defence Department, built and launched a series of synchronous satellites ('Syncom'). The problem of achieving the correct orbit was solved by including in the satellite an apogee boost motor for changing from a highly elliptical transfer orbit into circular geostationary orbit.

Syncom I and II carried microwave transposers of restricted bandwidth; but Syncom III (launched on 19th August 1964) was used during the 1964 Olympic Games for the relaying of television pictures from Japan to the United States. The success of the experimental Syncom satellites led to an interim international agreement and the setting-up of the Intelsat organisation. The American Comsat Corporation was the managing company and the United Kingdom held (approximately) an 8 per cent share. The first operational communications satellite ('Early Bird', later redesignated 'Intelsat I') was launched in April 1965. It carried two transposers which could be used for either television or multichannel telephony. Originally, only black-and-white television was intended; but the system proved capable of relaying colour transmissions.

'Early Bird' entered service in July 1965. For the first few weeks it was made available, free of charge, for international television relays. During that period there were many interchanges of news and sports items and also an ambitious international programme

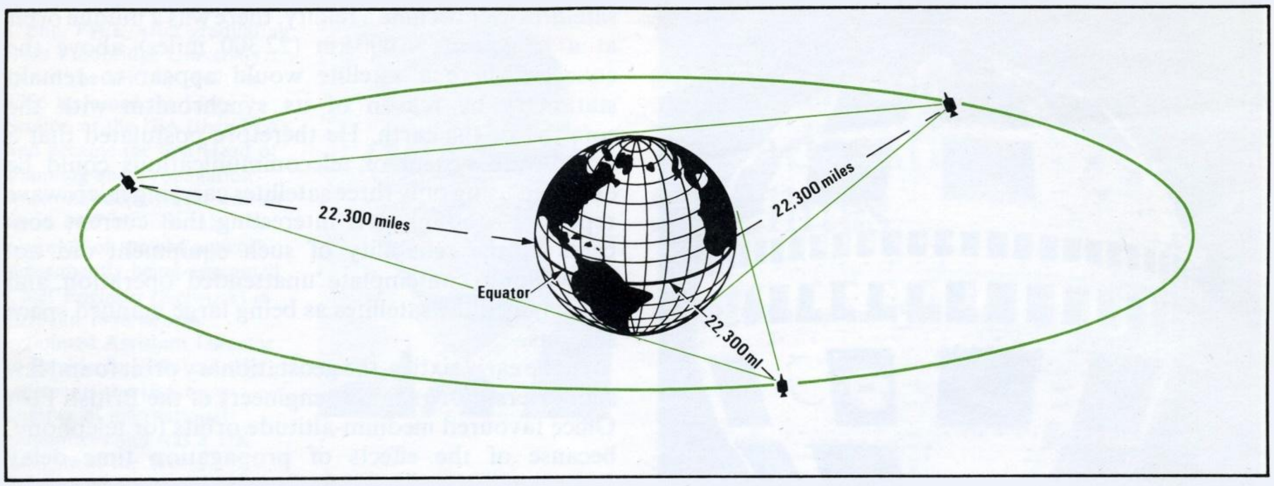


Fig. 2. In 1945 the British writer, Arthur C Clarke, proposed a system of extra-terrestrial microwave relays for world telecommunications, showing in his perceptive *Wireless World* article how the unique 'synchronous' or geostationary orbit 22 300 miles (approximately 36 000 km) above the equator would enable almost complete coverage of the populated areas of the world to be achieved from only three space platforms. A synchronous satellite is one which moves in a circular equatorial orbit, with a period exactly equal to that of the Earth's rotation, so that it appears to remain above a fixed point over the equator. However, such an orbit involves earth/satellite/earth propagation delays of the order of 270 milliseconds; and, for a number of years after the ability to launch artifical earth satellites was achieved in 1957, many engineers argued that such time delay would prove unacceptable for telephone conversations.

entitled 'Our World'. However, the subsequent imposition of commercial charges served to discourage transmissions other than major news and sports programmes. The scale of charges underlined to broadcasters that the wide bandwidth necessary for television transmission was capable of accommodating hundreds of more profitable telephone circuits: a problem which may be expected to last so long as satellite bandwidth fails to exceed greatly that required for intercontinental telephony, telex and data circuits.

The period 1965–71 saw the steady development of the international Intelsat system, successive generations of satellites offering more flexibility, greater bandwidth and longer design lifetimes. For example, the Intelsat IV series, of which the first came into service in January 1971, carries 12 transposers, each capable of carrying a 625-line colour television signal and using either wide beam or spot aerial beams. It has proved possible, at some loss of quality, to pass two television signals simultaneously through a single Intelsat IV transposer.

Satellites for Television Distribution

In parallel with the growth of the world-wide Intelsat system, the USSR has developed and launched a series of Molniya satellites to form their Orbita system. These satellites employ highly elliptical non-synchronous orbits, thereby affording good coverage in northern latitudes without need of fast-tracking earth stations. This system, in effect, pioneered the use of space satellites as a means of providing daily distribution of television signals over a large contiguous land-mass; for example, transmitting programmes from Moscow to Vladivostok in the Far East.

The use of space satellites for providing distribution links has, so far, proved the major application of satellites to broadcasting. The use of satellites for domestic communications is especially attractive where the terminals are widely separated by comparatively undeveloped areas. This encouraged Canada to set-up, as early as September 1969, 'Telesat Canada'; and, in 1971, to arrange for the launching of a series of 'Anik' satellites for domestic services, including television distribution to remote Arctic stations. In 1972 a control centre was established in Ottawa and the Canadian Broadcasting Corporation (CBC) contracted with Telesat the leasing of three satellite circuits. In November 1972 'Anik I' was launched; and, following initial use for telephony, telex and data, CBC had by February 1973 begun an interim service to the Yukon, British Columbia and the North-west Territories. Since then, additional Anik satellites have been launched, and the system now distributes television and radio programmes to a large number of locations throughout Canada, mainly (but not

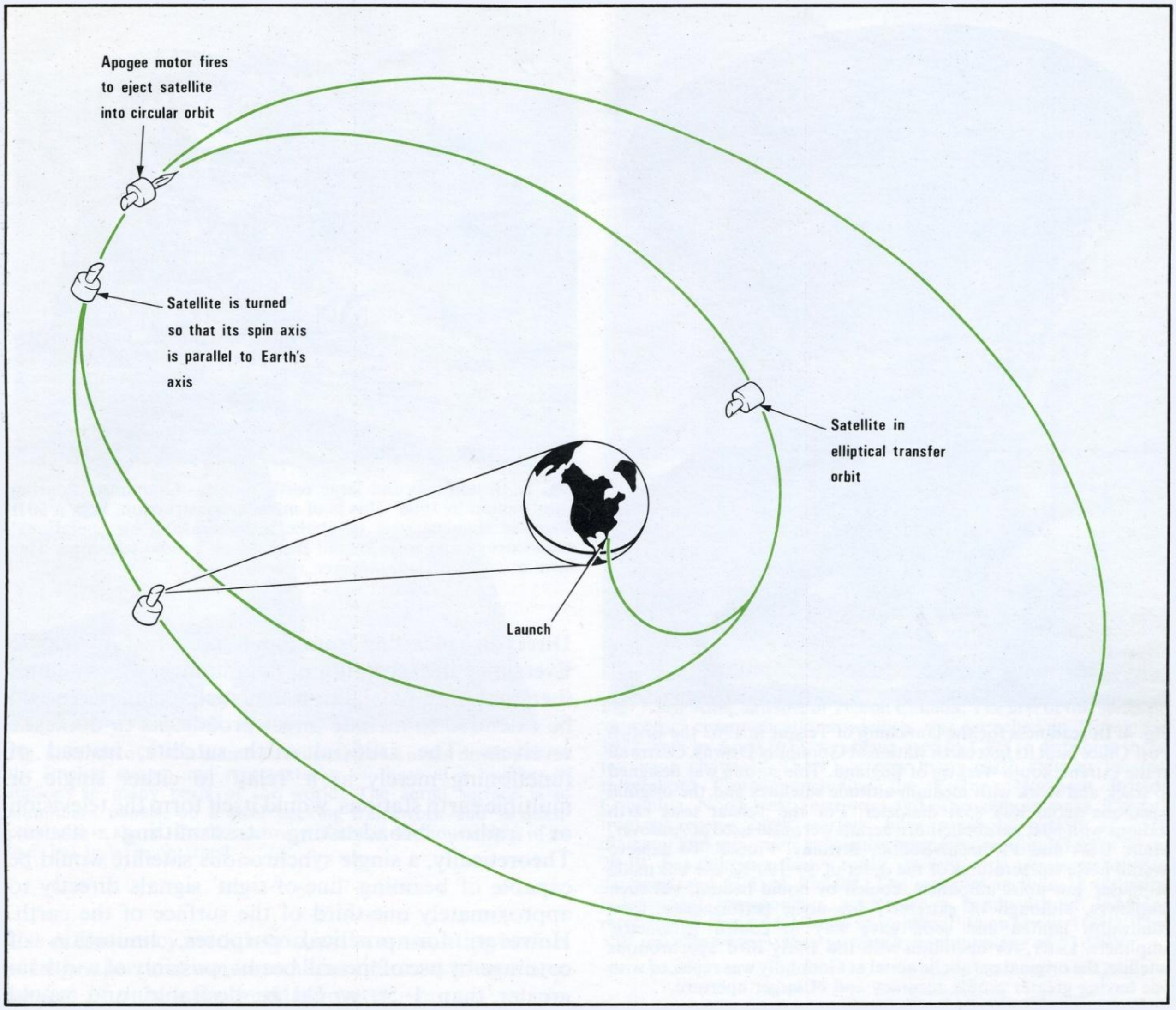


Fig. 3. How space satellites are launched into synchronous orbit. The satellite is initially put into a highly elliptical orbit beginning about 170 miles perigee. However, if the satellite velocity at this point is greater than that necessary to sustain such a low orbit, it will assume an elliptical orbit, rising to a much greater distance from Earth on the other side of the world. This is the apogee and is of the order of 22 300 miles high. At this point an apogee motor is fired which 'kicks' the satellite into a circular orbit by increasing its velocity to about 10 087 ft per second. Final adjustments to bring the satellite on station are applied by means of small gas jets using fuel carried within the satellite. The original 'Syncom' satellites launched in 1963 were spin-stabilised drum-shaped satellites 28-inches in diameter and 25-inches high, with the outside cylinder covered with 3840 solar cells providing about 25 watts of electrical power.

exclusively) in areas remote from large centres of population.

The use of 'domestic' satellite systems for the distribution of television and sound radio programmes is now being offered in countries with fully developed terrestrial microwave systems. For example, in the United States, distribution circuits and temporary links are now available via the 'Westar' satellites of Western Union and the 'Satcom' satellites of RCA. The Federal Communications Commission (FCC) has authorised the use in the USA of compact 'receive-only' terminals for the down links from satellites which provide, for example, 15 kHz sound circuits compared with the 5 kHz circuits generally used in the American long-distance terrestrial network.

A domestic satellite system, as an inherent feature of

Fig. 4. In readiness for the launching of Telstar in 1962 the British Post Office built its first earth station at Goonhilly Downs, Cornwall in the extreme south-west tip of England. This station was designed to track and work with medium-altitude satellites and the original parabolic aerial was 85 ft diameter. For the Telstar tests earth stations with 60 ft parabolic-horn aerials were also used at Andover, Main, USA and Pleumeur-Bodou, Brittany, France. To achieve overall noise temperatures of the order of 50–100°K, use was made of 'maser' low-noise amplifiers, cooled by liquid helium, but such amplifiers, although of extremely low-noise performance, were bandwidth limited and soon gave way to cooled parametric amplifiers. Later, for operation with the 'Early Bird' synchronous satellite, the original parabolic aerial at Goonhilly was replaced with one having greater profile accuracy and of larger aperture.

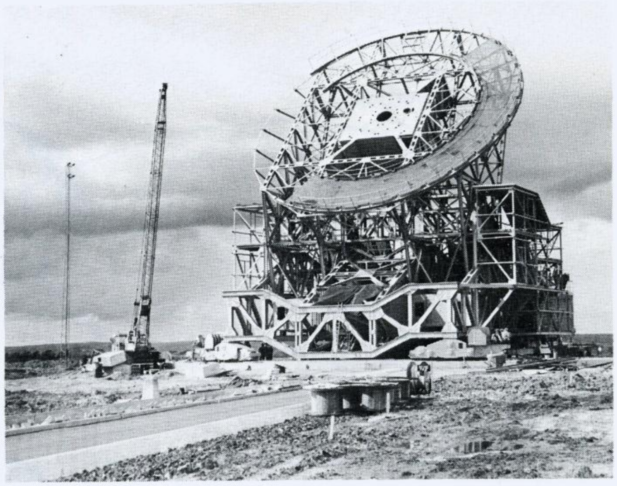


Fig. 5. Britain's second large earth station—Goonhilly 2 during construction in 1968. This is of massive construction, with a 90 ft diameter stainless steel parabolic aerial drawing on operational experience of the large Jodrell Bank Mark I radio telescope. This form of construction, however, is costly.

an expanded television service, is being established in Indonesia. It has a geostationary satellite located at 83° East for the relaying of television signals to a total of about 50 stations throughout the 26 Indonesian provinces. Another article in this volume of *IBA Technical Review* contains a detailed account of an experimental 12 GHz earth terminal set-up at the IBA Engineering Centre, Crawley Court. The terminal is used for investigations into a Eurovision satellite distribution network which may be established during the 1980s; in the long-term, the propagation studies should also prove valuable for direct-broadcasting to the home viewer.

Direct Broadcasting from Satellites

Ever since the inception of communications satellites there has been recognition that such techniques could be extended to include direct broadcasts to domestic receivers. The artificial earth satellite, instead of functioning merely as a 'relay' to either single or multiple earth stations, would itself form the television or radio broadcasting transmitting station. Theoretically, a single synchronous satellite would be capable of beaming 'line-of-sight' signals directly to approximately one-third of the surface of the earth. However, for practical purposes, limitation of coverage by use of 'pencil' beams, possibly of width no greater than 1–5°, would be desirable, and would permit the use of more realistic transmitter powers.

At first, it was thought that the limitations of solar cells would preclude direct broadcasting from satellites; and the possibilities of developing compact nuclear generators or fuel cells were considered. The exploitation of nuclear power in space was subsequently felt less likely because of the possible risk to the public and to the on-board electronic components. Also, progress in fuel-cell development has proved difficult and slow. Very large arrays of solar cells are safe; and use of these became more practicable when it was no longer necessary to limit the cells to the main body of the satellite.

The original estimates of power for amplitude-modulated satellite systems were of tens of kilowatts.

Fig. 6. Model of a 90 ft diameter, fully-steerable aerial developed for the Intelsat system and representative of those at a number of stations in many parts of the world. The aerial surface is of aluminium panels, on a steel backing framework and is quasi-parabolic in shape. Profile accuracy of about 40-thousandths of an inch has to be maintained.

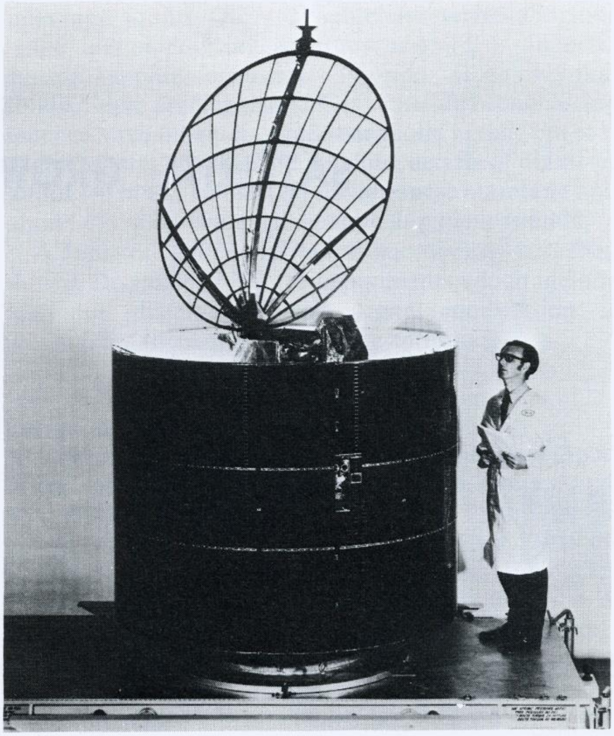


Fig. 7. An 'Anik' satellite of Telesat Canada. The first of this series of 'domestic' communications satellites was launched in November 1972, and, by April 1973, was being used by CBC to distribute three television channels. There are now many earth stations located throughout Canada including the Yukon, Northern British Columbia, North-west Territories and other remote areas. Typical transmit/receive earth stations have parabolic aerials of 33 ft diameter and minimum gain/noise temperature ratio (G/T) of 26 or 28 dB; but there are 'heavy route' stations with aerials up to 98 ft diameter and G/T of 37·5 dB. The satellites include 12 virtually independent transponders, each with a bandwidth of 36 MHz, receiving on about 6 GHz and re-transmitting on about 4 GHz. The 5 W travelling-wave-tubes provide a minimum erp of 33 dBW.

Use of frequency modulation, with transmitting aerials of large aperture, would require minimum transmitter powers of only a few hundred watts.

Satellites of larger size and weight were developed during the 1960s. Whereas the final orbital weight of 'Early Bird' (Intelsat I) was only 85 lb, that of Intelsat IV was 1075 lb. Thus, larger arrays of solar cells were used; and effective radiated powers increased, from the few watts of 'Syncom' and 'Early Bird' to kilowatts for wide-angle coverage, and to tens of kilowatts for 'pencil' beams.

So, by the late 1960s, it was entirely feasible to contemplate the use of satellites for international radio broadcasting; and various proposals were made for using them (with conventional hf domestic receivers) in the 26 MHz hf broadcasting band. However, those proposals were not implemented.

International agreements reached at the ITU World Administrative Radio Conference for Space Telecommunications (held at Geneva in June/July 1971) restricted frequency allocations for space broadcasting to parts of Band V (620–790 MHz); 2500–2690 MHz (not all available in Region 1); 11·7–12·5 GHz; 22·5–23 GHz (Region 3—Asia and Oceania only); 41–43 GHz; and 84–86 GHz. Subsequently, a further World Administrative Radio Conference in 1977 produced a World Agreement, and a Plan for Regions 1 and 3, for the 11·7–12·5 GHz band as described elsewhere in this volume. Since Band V is already fully utilised for terrestrial broadcasting within Europe, it is not expected that use will be made of this band for space broadcasting in the United Kingdom.

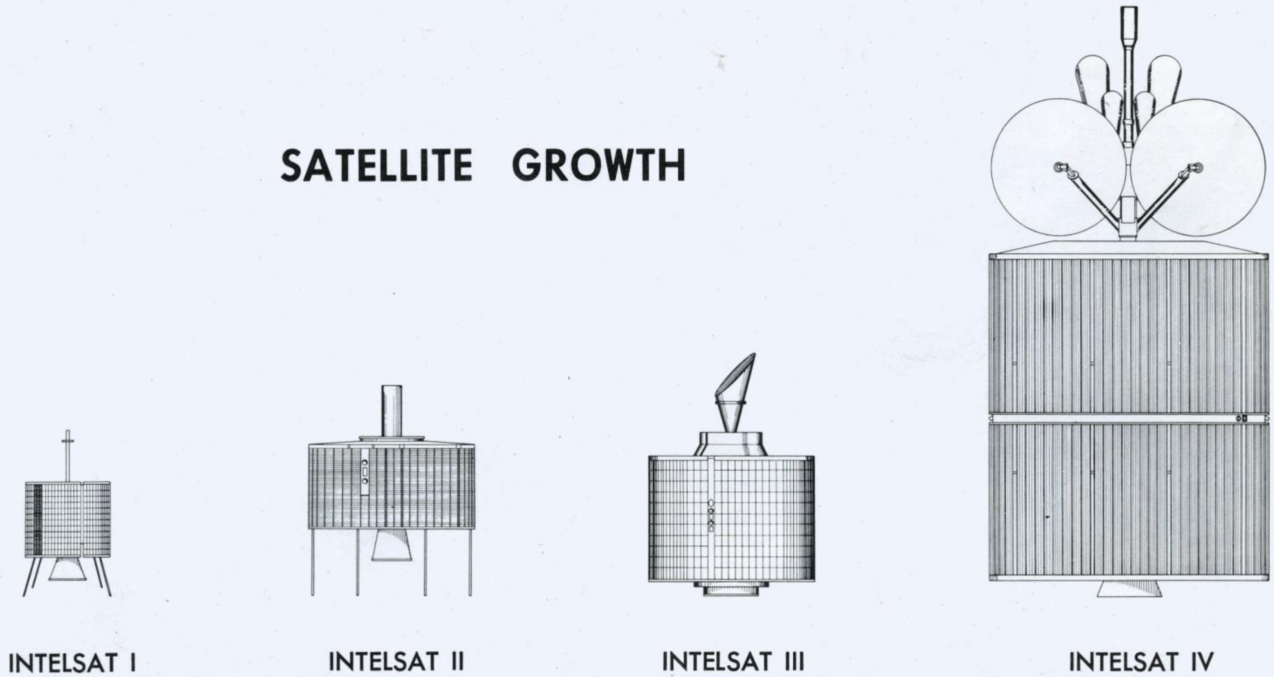


Fig. 8. The growth in size and capacity of the synchronous satellites used in the Intelsat system during the first decade of commercial operation.
Intelsat I had a diameter of 28·4 in, drum height 23·25 in weighed 150 lb at lift-off and 85 lb in orbit. No provision was made for multiple-access working.
Intelsat II had a diameter of 56 inches, drum height 26·5 in., weighed 357 lb at lift-off and 192 lb in orbit. Transponders permitted multiple-access working.
Intelsat III had a diameter of 56 in., overall height 78 in., weighed 632 lb at lift-off and 322 lb in orbit. The 10 720 solar cells provided about 130 watts of electrical power.
Intelsat IV had a diameter of 93·5 in., solar drum height of 9 ft 3 in., overall height 17 ft 6 in., weighed 2452 lb at lift-off and 1075 lb in orbit. Altogether some 50 000 solar cells provide sufficient power to permit an erp of about 1·9 kW for the 17° beam and 38 kW for the 4·5° beam (rf power about 80 W).

Satellite Instructional Television Experiment

One of the most interesting experiments in 'community' broadcasting from a satellite was the Indian Satellite Instructional Television Experiment (SITE) from 1st August 1975, to 31st July 1976. During that period an American Applications Technology Satellite (ATS-6) was made available to the Indian Government and used for transmitting television programmes to some 2400 villages spread over six Indian states. The television programmes were beamed to the satellite (stationed over Africa) from Ahmedabad, Western India, and then re-transmitted on about 860 MHz using in space a parabolic aerial of almost 10 m diameter. Programmes were transmitted for about 4 hours per day: $1\frac{1}{2}$ hours for schools in the mornings; $2\frac{1}{2}$ hours for the adult villagers in the evenings.

Canadian 'Hermes' Experiment

Canada and the USA have co-operated in an experimental Communications Technology Satellite (CTS) project and the satellite, now known as 'Hermes', was launched in January 1976 carrying a powerful 12 GHz transmitter. The signals from this satellite (placed in geostationary orbit over the equator at longitude 116°W) have proved sufficiently powerful to allow reception of frequency-modulated television pictures on a 0·6 m (2 ft) parabolic aerial with a relatively low-cost electronic 'front-end'. The special travelling-wave-tube amplifier has an efficiency greater than 50 per cent and provides a minimum output of 200 W at 12 GHz. The three-axis stabilisation system maintains altitude of the spacecraft with sufficient accuracy despite the large and flexible appendages. These include the solar cell panels which provide some 1·2 kW of electrical power.

As a result of the 'Hermes' experiments it has been suggested by Dr Christos A Siocos of CBC that 'the technical feasibility of a broadcasting service, either for

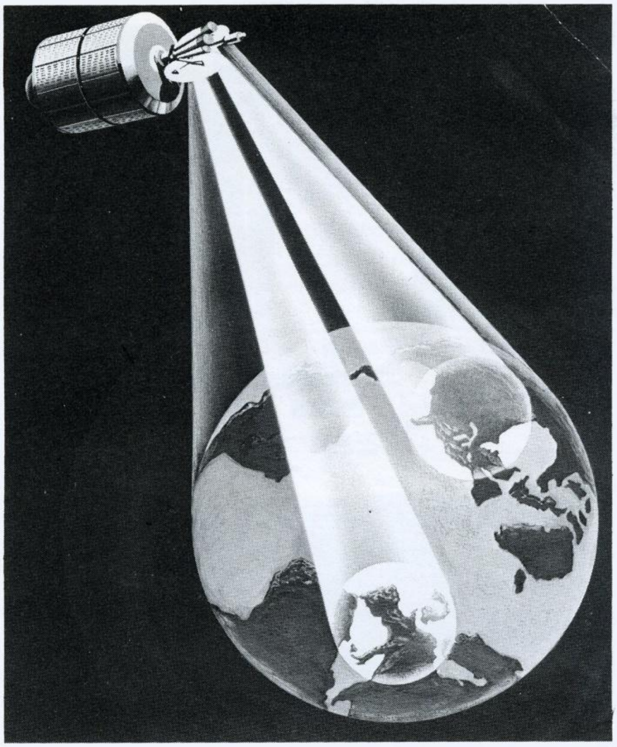


Fig. 9. The introduction of 'spot' as well as 'global' beams into the Intelsat series of communications satellites meant that effective radiated powers could be increased to tens of kilowatts. Spot beams are an essential requirement for direct broadcasting satellites to provide coverage of individual countries.

direct-to-home or for community reception, is a fact. What remains to be seen now is if this new technological capability can be used to advantage economically'.

Japanese Broadcast Satellite Experiment

A Japanese broadcast satellite for experimental purposes, known as BSE, is due to be launched during 1978 on a US launch vehicle. This is a medium scale, three-axis stabilised spacecraft with two sets of 14/12 GHz 100-watt transponders, to be placed over the equator at longitude 110°E. The television up-links will be on 14 GHz and the down-links on approximately 12 and 12·1 GHz. The satellite has a design life of 3 years and should provide a power flux density (pfd) of $-108\,\mathrm{dBW/m^2}$ over the Japanese mainland. The solar array will provide almost 1 kW of power. The satellite has capacity for two colour television channels with received quality for video intended to equal 45 dB signal noise ratio at 1 dB rain loss (TASO Grade 1) and 50 dB signal noise ratio for television sound. Other design characteristics include ±0·2° aerial pointing accuracy and ±0·1° on orbit station-keeping accuracy. Nippon Hose Kyokai (NHK) have developed a 12 GHz satellite broadcasting receiver with 0·6 m diameter parabolic aerial; but it is expected that, for the BSE satellite, aerials of diameter about 1·6 m will be used on the Japanese mainland and about 4·5 m on the more remote Japanese islands.

A Japanese CSE satellite was successfully launched during December 1977 for experiments which include television distribution and digital modulation at 27–30 GHz to compact receiving terminals.

European Orbital Test Satellite

An Orbital Test Satellite (OTS) has been developed under the aegis of the European Space Agency and was finally launched on 11th May 1978 into a geostationary orbit at longitude 10° East. This is intended as the forerunner of an operational European Communications Satellite (ECS) system which it is hoped will become operational in the early 1980s and might be used either to replace or to supplement the 'Eurovision' terrestrial television and sound distribution system.

The European Space Agency, formed in April 1975, combines the functions of two earlier European space organisations: ESRO (European Space Research Organisation) and ELDO (European Launcher Development Organisation).

OTS will transmit at frequencies in the region of 11 GHz and thus provide propagation characteristics very close to those of the Band VI (11·7–12·5 GHz) satellite broadcasting band.

It is a three-axis stabilised vehicle with a design life of three years. The solar arrays are on hinged panels independently steered to track the Sun. It is hoped to prove the design of telecommunication equipment to be used later in the operational ECS system and to make propagation measurements to furnish data which can then be used in the planning of future systems.

An experimental 11–12 GHz earth station has been built at the IBA Engineering Centre, Crawley Court for use in conjunction with the OTS satellite; this installation is described in detail elsewhere in this volume.

When, in September 1977, the initial launch of OTS failed due to a fault in the Thor Delta rocket, it was found that beacon signals from the Italian SIRIO experimental communications satellite were available on a frequency of 11·596 GHz. SIRIO is located in

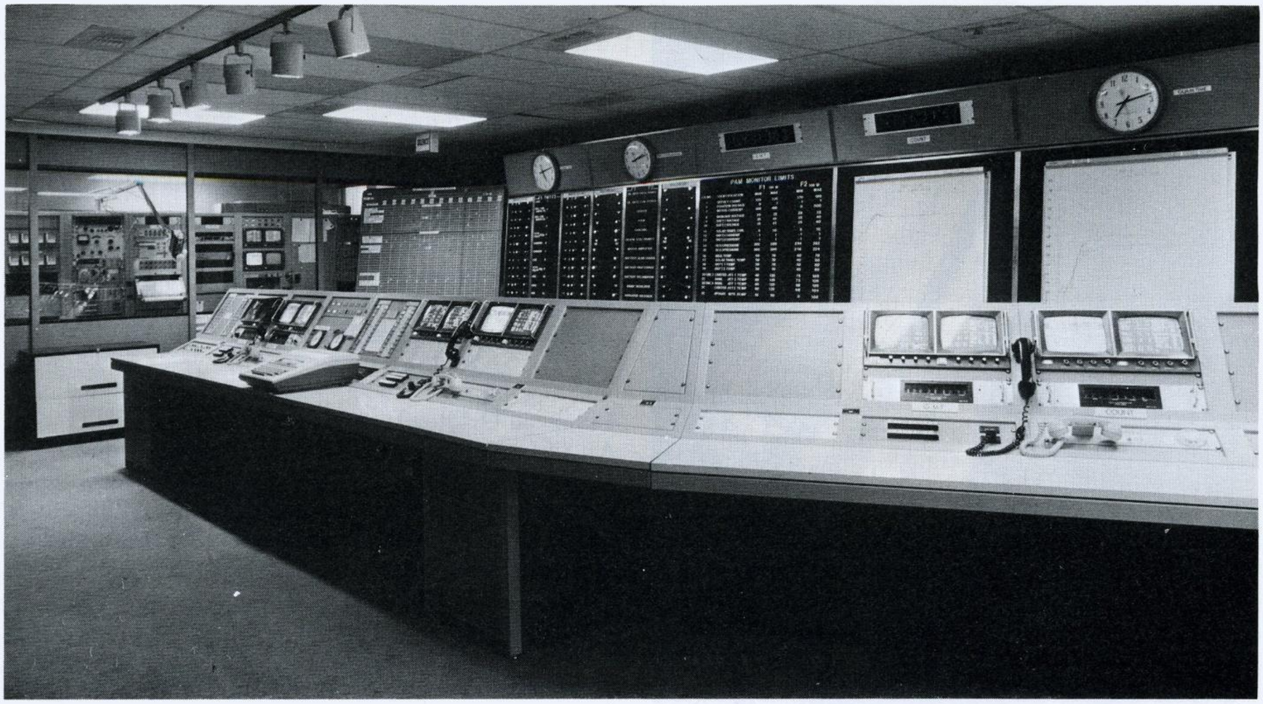


Fig. 10. The satellite control centre for the Telesat Canada system located in Ottawa. This operates in conjunction with tracking, telemetry and command stations at the large 'heavy route' earth stations at Allan Park, Ontario and Lake Cowichan on Vancouver Island. During launches a station on Guam in the Pacific is also used. Typically video snr (peak-to-peak picture signal to rms weighted noise) is designed to be 54 dB for network television and 52 dB for other earth stations.

synchronous orbit above the Equator at a longitude of 15° West. These signals are being used for preliminary studies of 11–12 GHz propagation.

The IBA receiving terminal has a 3 m diameter Cassegrain-fed parabolic aerial designed for good cross-polarisation performance. The low-noise amplifier is a parametric unit with a 17 dB gain and a noise temperature of 180°K.

The EBU requirements for Eurovision include coverage of North Africa and the Eastern Mediterranean area, and will demand the more or less dedicated use of two transposers, each capable of carrying one PAL or SECAM colour television channel, one high quality sound programme channel, 20 commentary circuits and a number of control and service circuits.

ITU World Agreement

The realisation of direct broadcasting and of distribution links took a significant step forward in January/February 1977 when a 'World Agreement' and associated 'Region 1 and 3 Plan' were drawn up at an ITU World Administrative Radio Conference in Geneva. This is described in detail elsewhere in this volume, but it should be noted here that the plan allocates to the United Kingdom five assigned channels, each of which would be suitable for transmitting one frequency-modulated television signal together with its accompanying sound within the Band 11·7–12·5 GHz, from a geostationary satellite at an orbital position 31°W.

This plan has a nominal life of 15 years from 1st January 1979, although it is thought likely that only a small proportion of the assignments will be taken up during that period. In countries of comparatively small geographical size with an already well-developed terrestrial television network of transmitters, such as the United Kingdom, satellite broadcasting seems likely to remain economically unattractive for some time to come. However, in countries where television is less well developed, or in those having perhaps a large area and a sparse or widespread population and difficult terrain, direct satellite broadcasting would seem to be economically attractive. The 'Hermes'

satellite has shown the technical feasibility; much depends on economic considerations, particularly on the cost and reliability of the domestic terminal.

The increasing use of national satellite distribution circuits in North America would seem to prove the technological advantages and economic advantages of such systems in countries where long-haul distribution links are required for regular use, provided that reliability is sufficiently high to allow the users to dispense with 'back-up' terrestrial networks.

Arthur C Clarke, who in 1945 conceived the idea of synchronous communication satellites, has stated: 'What we are building now is the nervous system of mankind, which will link together the whole human race, for better or worse, in a unity which no earlier age could have imagined'. In contemplating, in calculated engineering terms, the rapid developments that have already occurred, it is necessary to remember also the social implications of what we are doing; we are creating complex international visual communication networks with the possibility (whether or not intentional) of high-grade television services that will leap across national boundaries; opening, ever wider, television's windows on the world.

K J HUNT, MA (Oxon), after studying at New College, Oxford, joined the BBC in 1962, working successively on television recording, service area planning and engineering information. In 1972 he joined the IBA as a senior engineer in the Network and Service Planning Department, where he is currently concerned with field strength surveys and station planning for television and radio.

The ITU Plan for Space Broadcasting

by Alfred Witham and Kenneth Hunt

A L WITHAM, OBE, MA, CEng, FIEE, Assistant Director of Engineering (Policy), IBA. A biographical note appears on page 4.

SYNOPSIS

The future development of satellite broadcasting in Regions 1 and 3 for the next fifteen years will be subject to a detailed Plan drawn up at a 1977 World Administrative Radio Conference. This article outlines the main recommendations of this ITU plan which allocates five programme channels for the United Kingdom from an orbital position of 31°W, a position to be shared with Ireland, Spain, Portugal and Iceland. It explains the 'equivalent protection ratio' and other technical criteria used to ensure a high standard of service, to be provided by a margin of the order of −31 dB co-channel interference level. Details are also given of the technical criteria which form the essential basis of the ITU Plan for Region 1.

The realisation of broadcasting from satellites direct to the domestic viewer took a significant step forward at a World Administrative Radio Conference (WARC) in Geneva in January–February 1977. The conference produced a world agreement together with an associated plan for satellite broadcasting services in Regions 1 and 3 (most of the world except the Americas). The countries of Region 2 (the Americas) decided that it would be premature to formulate a detailed plan and instead adopted a set of interim provisions pending a further planning conference for Region 2 to be held in 1982.

The conference was concerned with the satellite broadcasting frequency band 11·7–12·5 GHz for Region 1 which includes Europe and Africa and 11·7–12·2 GHz for Regions 2 and 3. The agreed plan is based on the allocation to every country of a number of frequency channels at one or more defined orbital positions. Each assigned channel would be suitable for transmitting one frequency-modulated television signal together with its accompanying sound channel. Alternatively, any other signal occupying the same bandwidth and having an interference potential no greater than that of an fm television signal could be used.

The United Kingdom was allocated five of these channels at an orbital position of 31° longitude West (0° latitude) above the South Atlantic and close to the most easterly point of Brazil. The plan provides also the same orbital position for Ireland. This will facilitate the reception in each country of the programmes intended for the other, although the Irish transmitted beam, being smaller, will be more difficult to receive in England and Scotland. Apart from Ireland, the same

orbital position is assigned to Spain, Portugal and Iceland. The other European countries have been assigned different orbital positions, and it is generally accepted that it would normally be impracticable for domestic parabolic receiving aerials in this band to be readily redirected from one orbital position to another.

This limitation was much in mind at the conference and several countries sought to share orbital positions with specific countries. Examples of such groupings were:

France, West Germany, Belgium, Netherlands, Luxembourg, Italy and Austria;
Poland, East Germany, Czechoslovakia, Hungary, Roumania and Bulgaria;
Norway, Sweden, Finland and Denmark;
Libya, Tunisia, Algeria and Morocco.

Unlike terrestrial television, the signal level from a satellite attenuates only gradually outside the planned service area, so that, in the absence of interference, signals could be received by using more sophisticated receiving installations far outside the country for which those signals were intended. However, if the plan were to be implemented as a whole, the coverage outside the planned service area would soon be limited by interference. In the early years, when only few allocations may be in use, interference levels are likely to be much lower than those indicated in the plan, so that reception over quite wide areas will be technically possible; it remains to be seen whether the viewing public will wish to make significant use of this possibility.

The plan has a nominal life of fifteen years from the date at which it will come into force, i.e., 1st January, 1979. There is no certainty that more than a small proportion of the assignments will be taken up during these fifteen years. In countries of comparatively small geographical size, already having a well developed terrestrial television service, as in the UK, satellite broadcasting may currently appear economically unattractive, despite offering the possibility of five extra nationwide programme channels. However, in countries where television is less well developed, where there is a very large area, with sparse or widespread populations and difficult terrain, satellite broadcasting might within those fifteen years be economically attractive. China, the eastern parts of the Soviet Union, and certain countries in Africa and the Middle East are all examples where early development of direct satellite broadcasting may be favoured, as an alternative to terrestrial or balloon-borne transmitters.

Within Europe, the Nordic group of countries (Norway, Sweden, Finland and Denmark) have also shown particular interest in satellite broadcasting, even though high latitudes are not ideal for coverage from satellites. These countries have negotiated a 'supranational' beam to provide a larger coverage area extending over a large proportion of the Nordic area.

Equivalent Protection Margins

The Plan for Regions 1 and 3 specifies frequencies and orbital positions to minimise interference between the various assignments by making use of four different characteristics: receiver selectivity; receiving aerial directivity; transmitting aerial directivity; and polarisation discrimination. To assess the quality of the plan, each assignment is judged by a single criterion, the 'equivalent protection margin'. This is a measure of the effective sum of co-channel and adjacent-channel interference. The equivalent protection margin is numerically the value in dB by which the ratio of wanted signal to total interference exceeds the agreed co-channel protection ratio. The protection ratios adopted when calculating the equivalent protection margin for the satellite plan are 31 dB for co-channel interference and 15 dB for adjacent-channel interference.

There are agreed reference patterns, designed by the International Radio Consultative Committee (CCIR) for directivity of receiving aerials and for transmitting aerials. Since the receiving aerial is assumed to be directed towards the orbital position of the wanted satellite, the effect of its directivity is dependent upon the orbital separation between the wanted and the interfering satellite signals. In relation to transmitting aerial directivity it should be noted that the level of interference may be reduced by increasing the geographical separation between the intended service area and the service area of the signals which cause interference. However, since the International Radio Consultative Committee (CCIR) reference pattern is normalised in relation to the beamwidth of the transmitting aerial, broad beam patterns lead to interference at a greater distance from their intended service areas than narrow beams.

Interference may be reduced by ensuring that the interfering signal has an opposite direction of polarisation to that of the wanted signal. The degree of discrimination provided by the use of opposite circular polarisation, when added to receiver selectivity, sufficiently reduces the level of interference to permit the use of adjacent channels for contiguous areas.

In a few instances, the agreed frequency assignments do not quite reach the agreed protection ratio of 31 dB;

however that figure represents a very high standard, and, even at, say, 28 dB, picture quality would still be very good.

Spillover

Since countries are of no regular size and shape, any practical satellite aerial with an elliptical beam designed to serve the whole of a particular territory must usually cover some parts of neighbouring countries, causing what is termed *spillover*. This is exaggerated by the need to allow a margin of at least 0·1° for East–West and North–South satellite station keeping and 2° for satellite rotation about the beam axis. A minimum practicable transmitting beam is considered to be circular with a diameter subtending to an angle of 0·6°, which is larger than required to cover certain small countries. In such cases the effective radiated power should be reduced to produce the agreed value of power flux density (pfd) of $-103\,\mathrm{dBw/m^2}$ at the limit of the desired service area.

During the WARC, certain equatorial countries claimed that they hold sovereign rights over the section of the equatorial geostationary orbit above their territory, and that any assignment of such orbital positions requires their express permission. This view is not shared by non-equatorial countries, and the Final Acts contain both reservations and formal statements in opposition (including one by the United Kingdom). Whatever the precise application of satellite broadcasting in the future, the plan establishes a framework for its disciplined growth. Administrations can also now plan other uses of the 11–12 GHz band in the knowledge that its potential use for satellite broadcasting is clearly charted for a number of years ahead.

Technical Characteristics

The system selected as the basis for planning is frequency modulation with a bandwidth of 27 MHz and early planning studies assumed that channel spacing would be at least equal to the bandwidth. However, it was subsequently appreciated that more effective use of the frequency band would result from making channel spacings narrower than the required bandwidth. Although this results in an increase in adjacent channel interference (from overlapping channels) the increased number of channels gives a reduction in co-channel interference as well as permitting the allocation of more channels per country. In general terms, there is a quasi-optimum condition where the total of the co-channel contributions (on a power sum basis) equals that of the adjacent channel contributions.

A total of 40 channels spaced at 19·18 MHz has been planned, with a guard band at each end of the band.

Before it is possible to specify the pfd needed to provide a satisfactory service, the characteristics of receivers must be assumed, at least in general terms. For planning purposes a gain/noise-temperature ratio (G/T) of 6 dB/°K has been assumed, together with a maximum aerial beamwidth of 2° (1·8° in Region 2), leading to a pfd limit at the edge of the service area of $-103\,\mathrm{dBw/m^2}$ ($-105\,\mathrm{dBw/m^2}$ in Region 2) for individual domestic reception.

On the basis of continuous interference levels, the picture impairment is specified for planning purposes as no worse than Grade 4·5 (using the CCIR five-point scale).

To achieve this aim, both transmitting and receiving aerials must be closely controlled, especially as to the suppression of the sidelobes for both wanted and unwanted polarisation. The specified patterns are in terms of angle relative to half the beam width (which in turn is specified as the -3 dB point). Transmitting aerials may be expected normally to have elliptical patterns so that sidelobe suppression will be a function of the beam orientation; receiving aerials will need only a circular beam and, in practical terms, the beam width of 2° approximates to a parabolic aerial diameter of about 0·9 m.

The pfd in the centre of the service area is assumed to be 3 dB higher than that at the edges. For small countries a transmitting beam width limit of 0·6° implies that the equivalent isotropically radiated power (eirp) of the transmitter will be reduced to give $-103\,\mathrm{dB/m^2}$ pfd at the edge of the service area, although this means less than $-100\,\mathrm{dB/m^2}$ at the centre.

It is expected that it will soon be practicable to generate shf power of 1 kW per satellite, increasing to 4 kW later. For a free-space loss of 205 dB and the required pfd, this power level represents a beam area (product of major and minor beamwidths) of about 5·6° squared for each channel. If five national channels are to be provided from one satellite the maximum beam area becomes about 1·1°. There is an advantage to be gained by positioning a satellite well to the east or west of its service area since this reduces the beam area. However, to continue broadcasting after midnight at all periods of the year, it is necessary to place the satellite to the west of its service area to avoid the effect of the Earth eclipsing the satellite during Spring and Autumn equinoxes.

For a satellite position much to the west (or east) of its service area, the elevation angle of the satellite as

seen from the receiver decreases, causing additional attenuation of the signal path during precipitation. The difference in attenuation between clear weather conditions and 1 per cent of time in the 'worst' month should not exceed 2 dB: this sets a lower limit on acceptable elevation angles. The angle depends upon climatological conditions within the service area. For the most northerly parts of the UK it is about 17°.

Countries in extreme northern latitudes or those with very high rainfall (usually near the Equator), have to accept large beam-widths in order that the elevation angles shall be high.

Circular polarisation is used rather than linear. Although suffering the disadvantage of some depolarisation during precipitation, circular polarisation has the advantage that the discrimination is maintained at off-axis angles where little polarisation discrimination can be provided when using linear polarised signals. This is not a function of aerial performance but results from geometrical considerations.

Circular polarisation is also advantageous should there be any rotation of the beam about its axis. This is because, to areas using orthogonal polarisation, there is no increase in interference other than that caused by movement of the beam 'foot-print'.

The United Kingdom has been alloted channels 4, 8, 12, 16 and 20 in the lower frequency portion of the band; and, for the rest of Europe, each country will have a similar distribution ($n, n + 4, n + 8$ etc.) so that eight countries will share each satellite location (all 40 channels are allotted for each orbital position serving European countries). For example, the 19°W position is shared by France, West Germany, Luxembourg, Austria, Belgium, Switzerland, Netherlands and Italy. Countries in other geographical areas may re-use channels from a common orbital position; for example, 19°W is also intended for several African countries. To make maximum use of polarisation discrimination, the transmissions for Europe from 19°W will use direct and indirect polarisations in odd and even numbered channels, while those for Africa will use indirect and direct polarisation respectively.

Continuing this process, the adjacent orbit locations (13°W and 25°W) use direct and indirect polarisations on even and odd channels in Europe and the reverse polarisations in Africa. Thus, for any particular geographical area, the same channel and polarisation is used only at alternate orbital positions.

Band Sharing

For Europe, band sharing represents the re-use of frequencies between 11·7 and 12·5 GHz for terrestrial purposes such as microwave links carrying telephony or television signals or a terrestrial television broadcast service. Additionally, in Region 2, there are certain proposed fixed satellite services to be considered.

For telephone links using frequency modulation, relatively narrow channels are involved. By reason of this, some sections of the fm television broadcast spectrum from the satellite would have high energy contents within narrow bands. Therefore, special measures need to be taken. Hence, the broadcasting plan calls for the use of energy dispersal by the addition to the television signal of a low-frequency triangular waveform prior to vision modulation. The result is to provide a deviation of about 600 kHz in the absence of any other modulation. At the receiver, this dispersal waveform can be removed from the incoming signal by means of a fairly simple circuit. Thereby, the protection ratio at the input of a 4 kHz telephone channel is improved by about 22 dB.

It seems unlikely that in any particular country, domestic receiver characteristics will permit widespread terrestrial re-use of that half of the 11·7 to 12·5 GHz band unused by the satellite broadcasting service of that country. The unused half of the band allotted to the UK will be used by Belgium, Holland and Norway, all of which have oversea paths from the UK. Thus, it would seem that, within the UK, any terrestrial re-use of the band would be much restricted in southern and eastern areas, but possibly feasible elsewhere.

F H WISE, BSc, FIERE, graduated from Southampton University and then joined Vickers–Armstrong (Aircraft) Ltd, where he worked on uhf receiving systems and flight simulators. In 1958 he joined the IBA and is currently Head of the Network and Service Planning Department. He is a member of CCIR Study Group 10 and of the EBU Working Parties R1 and S.

Fundamentals of Satellite Broadcasting

by Frederick Wise

SYNOPSIS

This article surveys the basic factors governing area-coverage by means of a 12 GHz satellite system. Descriptions are given of free-space path loss, additional attenuation due to rain or precipitation in the atmosphere, the obtaining of sufficient power for satellite equipment and the necessary techniques for calculating the signal/noise ratio of pictures received by community and domestic installations.

The position of a broadcasting satellite may be defined by its longitude, Λ_s, the other co-ordinates being determined by its geostationary orbit. A receiving station at longitude Λ_r and latitude ϕ_r will have azimuth, elevation and path length as follows:

$$\text{Azimuth}\ (°) = \tan^{-1}(\tan\Lambda/\sin\phi_r) + 180°\ \text{ETN}$$
$$\text{where } \Lambda = \Lambda_r - \Lambda_s$$

$$\text{Elevation}\ (°) = \tan^{-1}[(\cos\beta - \sigma)/\sin\beta]$$
$$\text{where } \sigma = \text{radius of earth}/(\text{radius of earth} + \text{height of satellite})$$

For a geostationary orbit this is a constant equal to 0·151 269 and

$$\beta = \cos^{-1}(\cos\phi_r \cos\Lambda)$$

Path length (km)

$$d = 35\,786\sqrt{[1 + 0{\cdot}419\,99\,(1 - \cos\beta)]}$$

Satellite Coverage

Assuming that the coverage from a satellite extends to a distance E from the 'boresight' point (i.e., the point at which a directional antenna is accurately aimed), and the semi-beamwidth angle δ, an approximation of the egg-shaped coverage area can be calculated:

First we calculate azimuth (a), elevation (θ) and distance (d) for the boresight point as in the preceding section.

If δ is the semi-beamwidth in the appropriate direction:

$$a_1 = \frac{d\tan\delta}{\sin(\theta - \delta)} \qquad a_2 = \frac{d\tan\delta}{\sin(\theta + \delta)}$$

Then

$$E1 = a_1 + \frac{a_1^2}{2[r\tan(\theta - \delta) - a_1]}$$

$$E2 = a_2 - \frac{a_2^2}{2[r\tan(\theta + \delta) + a_2]}$$

where r is the radius of the Earth (i.e. 6386 km).

Coverage radius in transverse direction ($E3$) is simply:

$$E3 = d\tan\delta$$

As an example of such a calculation, the following coverage would be achieved with a geostationary satellite beam centred on a point near Stoke-on-Trent (2°W, 53°N) with an assumed satellite position of 25°W.

Boresight calculations:

Azimuth	208°
Elevation	26°
Distance	38 994 km

Semi-beamwidth angle	Coverage radius in km E1	E2	E3
0·25°	420	370	170
0·5°	940	690	340
0·75°	1600	990	510
1·0°	2600	1300	680

Path Loss

If we consider an isotropic point source radiating a power P watts, then the power flux density (pfd) at a distance of r metres is:

$$\text{pfd} = P/4\pi r^2 \text{ watts per square metre}$$

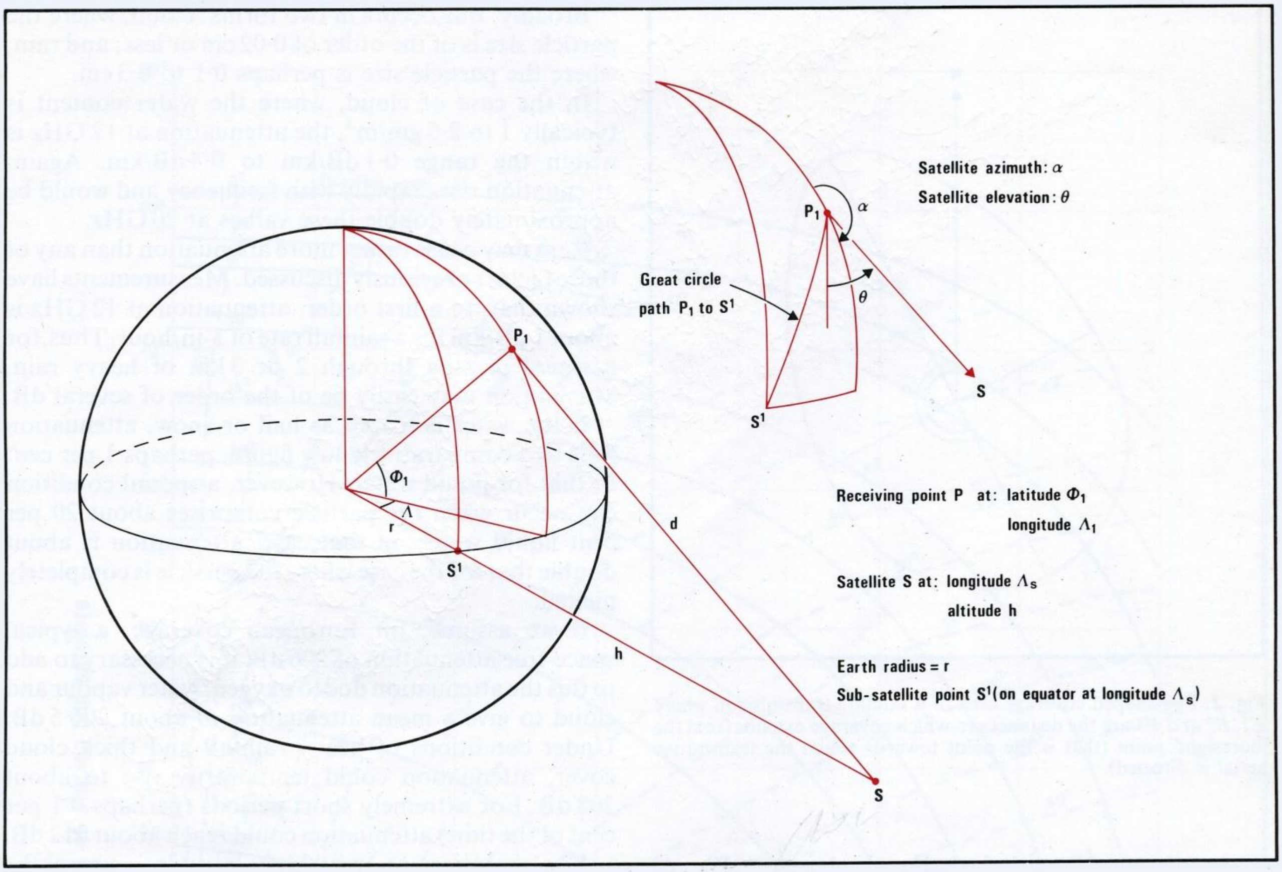


Fig. 1. The geometry of the synchronous satellite showing the symbols used in the calculations of satellite direction and path length. Since the satellite is located above the equator, its position is uniquely defined by its longitude, Λ_s.

The power radiated may be realised by the use of a transmitter of power P_t together with an antenna of gain G_t in the relevant direction.

The power available from a receiving antenna is:

$$P_r = \text{pfd} \times \text{absorptive area of antenna}$$

The absorptive area of an antenna is related to its gain (G_r) by:

$$\text{absorptive area} = G_r \lambda^2 / 4\pi$$

where λ is the wavelength of transmission.

We can thus derive the following expression for power received:

$$P_r = P_t \,.\, G_t \,.\, G_r \,.\, \lambda^2/(4\pi r)^2$$

where the term $\lambda^2/(4\pi r)^2$ represents the free space attenuation.

For a geostationary satellite with a transmission frequency of 12 GHz, the free space attenuation for European latitudes is rather less than 206 dB. For a point directly below the satellite it would be 205·1 dB increasing to 206·4 dB at the horizon 'seen' from the satellite. Thus for the United Kingdom:

$$P_r = P_t(\text{dBW}) + (G_t + G_r - 206)\,\text{dB}$$

Atmospheric Effects

At frequencies of the order of 12 GHz, the shf energy causes some sympathetic vibration of the molecules in the constituent gases of the atmosphere. In principle, energy coupled into the gases is freely convertible back into radio wave energy; but, in practice, some energy is lost due to molecular collision, resulting in some attenuation of the radio wave additional to the free-space attenuation.

For the two most important gases in this context—water vapour and oxygen—the manner in which

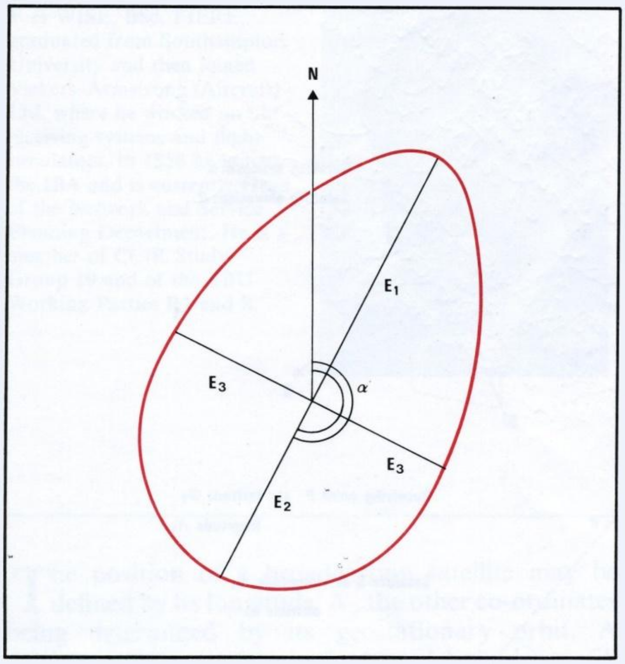


Fig. 2. Egg-shaped coverage area of a satellite transmission where *E1*, *E2* and *E3* are the distances to which coverage extends from the 'boresight' point (that is the point towards which the transmitter aerial is directed).

attenuation varies with frequency is shown in Fig. 4. These curves relate to attenuation at sea-level. Because the atmosphere becomes thinner with increasing height, the attenuation of signals arriving from a satellite is also reduced, values at a height of some 15 km to 20 km reaching only about 1 per cent of the sea-level figures.

For the purposes of calculation, it is convenient to consider an equivalent uniform atmosphere, having constant attenuation irrespective of altitude up to a height of 5 km, and then zero attenuation at greater heights. For European satellite elevations of roughly 20°–30°, the equivalent atmospheric path length is within the range 10–15 km. At 12 GHz, the curves of Fig. 4, indicate that path attenuation will be no more than about 0·1 dB each for oxygen and water vapour. However, Fig. 4 also shows that, at these frequencies, the attenuation of water vapour is rising rapidly and would reach 2 or 3 dB at 20 GHz.

Thus, at 12 GHz, attenuation due to atmospheric gases is of little practical importance; a more significant factor, however, is the presence of liquid water.

Broadly, this occurs in two forms: cloud, where the particle size is of the order of 0·02 cm or less; and rain, where the particle size is perhaps 0·1 to 0·3 cm.

In the case of cloud, where the water content is typically 1 to 2·5 gm/m^3, the attenuation at 12 GHz is within the range 0·1 dB/km to 0·4 dB/km. Again, attenuation rises rapidly with frequency and would be approximately double these values at 20 GHz.

Rain may cause rather more attenuation than any of those factors previously discussed. Measurements have shown that, to a first order, attenuation at 12 GHz is about 1 dB/km for a rainfall rate of 1-in/hour. Thus, for a signal passing through 2 or 3 km of heavy rain, attenuation may easily be of the order of several dB.

If the water is frozen as hail or snow, attenuation falls to a comparatively low figure, perhaps 1 per cent of that for liquid water. However, a special condition can occur when the particle comprises about 20 per cent liquid water; in that case, attenuation is about double that for the case where the particle is completely melted.

If we assume, for European coverage, a typical space-free attenuation of 206 dB, it is necessary to add to this the attenuation due to oxygen, water vapour and cloud to give a mean attenuation of about 206·5 dB. Under conditions of heavy rainfall and thick cloud cover, attenuation could temporarily rise to about 208 dB. For extremely short periods (perhaps 0·1 per cent of the time) attenuation could reach about 212 dB.

For reception at very high latitudes, where the elevation angle will be significantly reduced, the atmospheric attenuation will be greater, reaching perhaps 213 dB for 1 per cent of the time, and possibly as high as 220 dB for 0·1 per cent of the time.

Another propagation characteristic of microwave signals transmitted through the atmosphere of the Earth is that some scattering of the wave occurs, resulting in the generation of a cross-polarised component of the received signal. For circularly-polarised waves, the effect takes the form of the generation of a component with the opposite direction of rotation.

In general, the cross-polarised component of a satellite signal is relatively weak, although, under certain propagation conditions, and where reliance has been placed upon polarisation discrimination to facilitate service planning, it may be sufficiently strong to contribute to interference. As might be expected, the amount of scattering and consequently depolarisation, tends to increase with the amount of excess attenuation over the propagation path. Since, at UK latitudes, excess attenuation, as indicated above, will

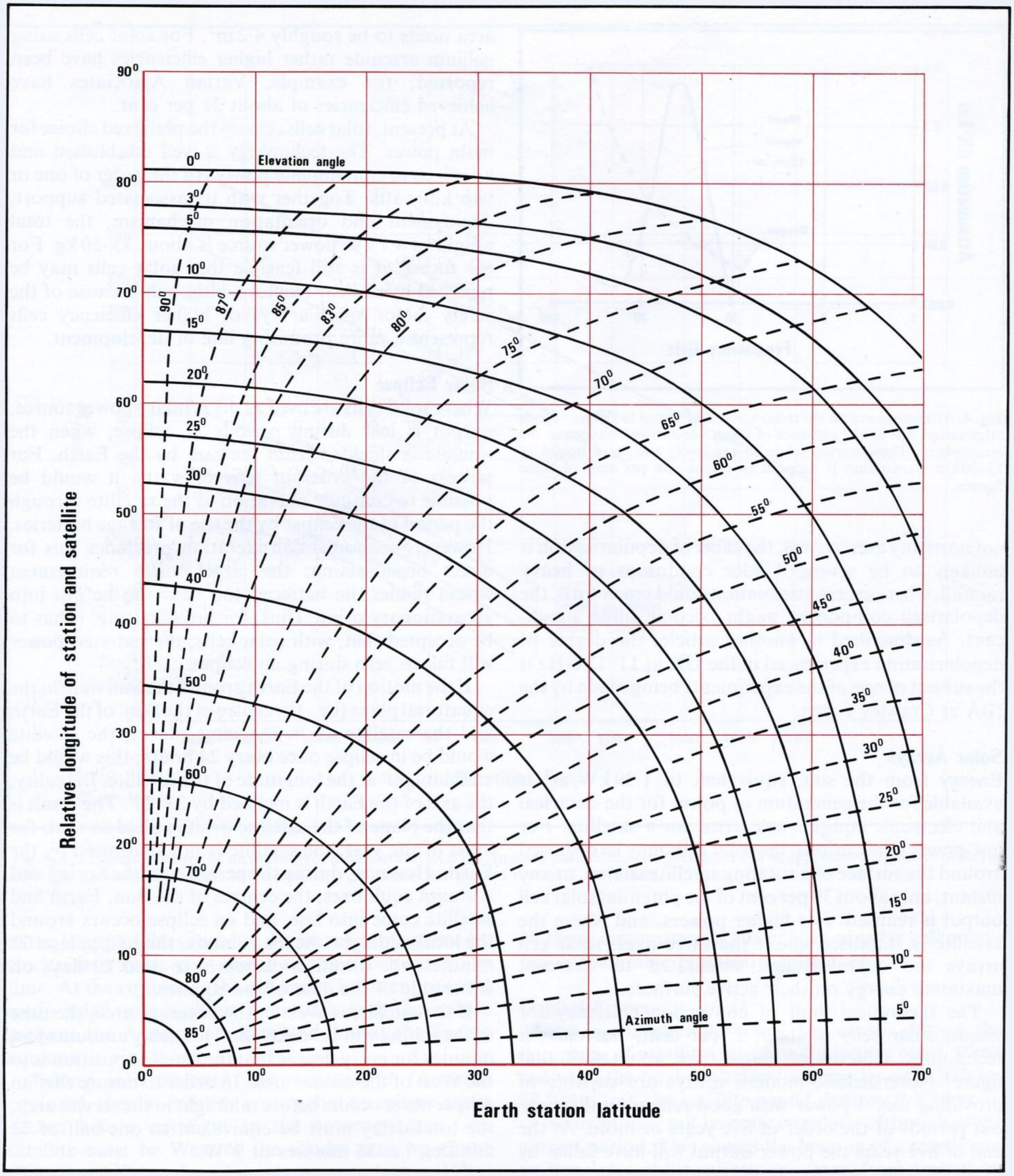


Fig. 3. Elevation and azimuth angles of synchronous satellites as 'seen' from earth stations on the basis of the latitude and relative longitude of the earth station and the orbital position of the satellite. The azimuth is shown as an acute angle to the local meridian and should be adjusted for quadrant inspection.

(*due to J K S Jowett, British Post Office*).

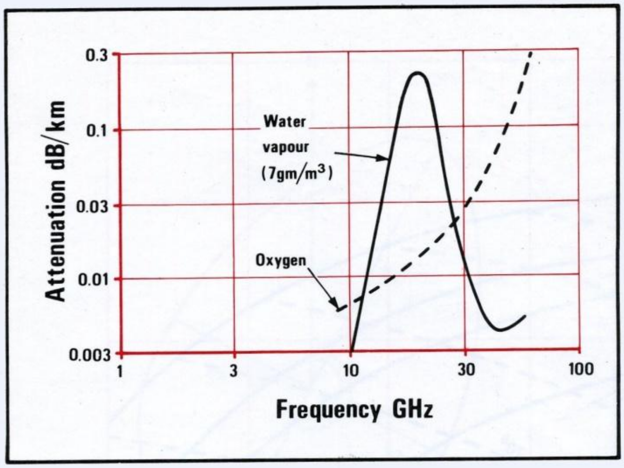


Fig. 4. Attenuation of an shf radio wave, additional to the free-space attenuation due to the presence of water vapour and oxygen in the atmosphere. These curves relate to sea-level; and, at a height of 15–20 km attenuation is reduced to about one per cent of these figures.

not normally exceed 2 dB, the effect of depolarisation is unlikely to be severe. Under conditions of heavy rainfall, where excess attenuation could reach 6 dB, the depolarised component might become quite significant. As described in another article, the degree of depolarisation experienced in the UK at 11–12 GHz is the subject of one of the experiments being made by the IBA at Crawley Court.

Solar Arrays

Energy from the sun, equivalent to $1{\cdot}39\,kW/m^2$ is available for the generation of power for the electrical and electronic equipment carried on a satellite. For low-power applications, the solar cells may be disposed around the surface of a rotating satellite so that, at any instant, only about 30 per cent of the potential solar cell output is realised. For higher powers, and where the satellite is stabilised about the three axes, solar cell arrays are deployed and orientated to intercept maximum energy on their active surfaces.

The theoretical limit of conversion efficiency for silicon solar cells is about 25 per cent, but current technology achieves no more than about half that figure. Nevertheless, modern arrays are capable of providing useful power with good reliability throughout periods of the order of five years or more. At the end of five years the power output will have fallen by about 20 per cent. Total power consumption for the planned Orbital Test Satellite (OTS) is 700 watts. Thus, assuming 12 per cent efficiency, the solar array area needs to be roughly $4{\cdot}2\,m^2$. For solar cells using gallium arsenide rather higher efficiencies have been reported; for example, Varian Associates have achieved efficiencies of about 21 per cent.

At present, solar cells remain the preferred choice for main power. The technology is well established and allows us to contemplate powers of the order of one or two kilowatts. Together with its associated support, deployment and orientation mechanism, the total weight of a 1 kW power source is about 35–50 kg. For the future, it is still feasible that solar cells may be replaced by nuclear reactors, although because of the safety factor solar arrays of higher efficiency cells represent a more promising line of development.

Solar Eclipse

Where solar cells are used as the primary power source, output is lost during periods of eclipse, when the satellite is shielded from the Sun by the Earth. For powers of the order of tens of watts, it would be possible to continue operation of the satellite through the period of the eclipse by the use of storage batteries. However, economic consideration precludes this for direct broadcasting; the large power requirement would render the batteries too heavy to be put into geostationary orbit. Thus, for broadcasting, it has to be accepted that, with solar cells, the radiated power will fall to zero during an eclipse.

If the motion of the Earth around the Sun were in the equatorial plane (i.e., the centre of the Sun, of the Earth and the satellite all in the same plane), the satellite would be in eclipse once every 24 hours; this would be at 'midnight' at the longitude of the satellite. In reality, the axis of the Earth is inclined by 23° 27′. The result is that the plane of the satellite orbit is tilted so that, for most of the year, the satellite is not shadowed by the Earth. However, during the period near the Spring and Autumn equinoxes, the centres of the Sun, Earth and satellite come into line, and an eclipse occurs around the local midnight. At the equinox, the eclipse lasts 72 minutes; the duration decreases to zero 22 days on either side of the date of the equinox.

If the satellite is West of the coverage area, the time of the eclipse will be 'delayed'. This delay amounts to 4 minutes for every degree that the satellite position is to the West of the service area. In order to ensure that an eclipse never occurs before midnight in the service area, the total delay must be equivalent to one-half of 72 minutes, i.e. 36 minutes or 9°W.

This calculation assumes that time is measured in true solar time. Because the orbit of the Earth is elliptical rather than circular, there is a slight variation

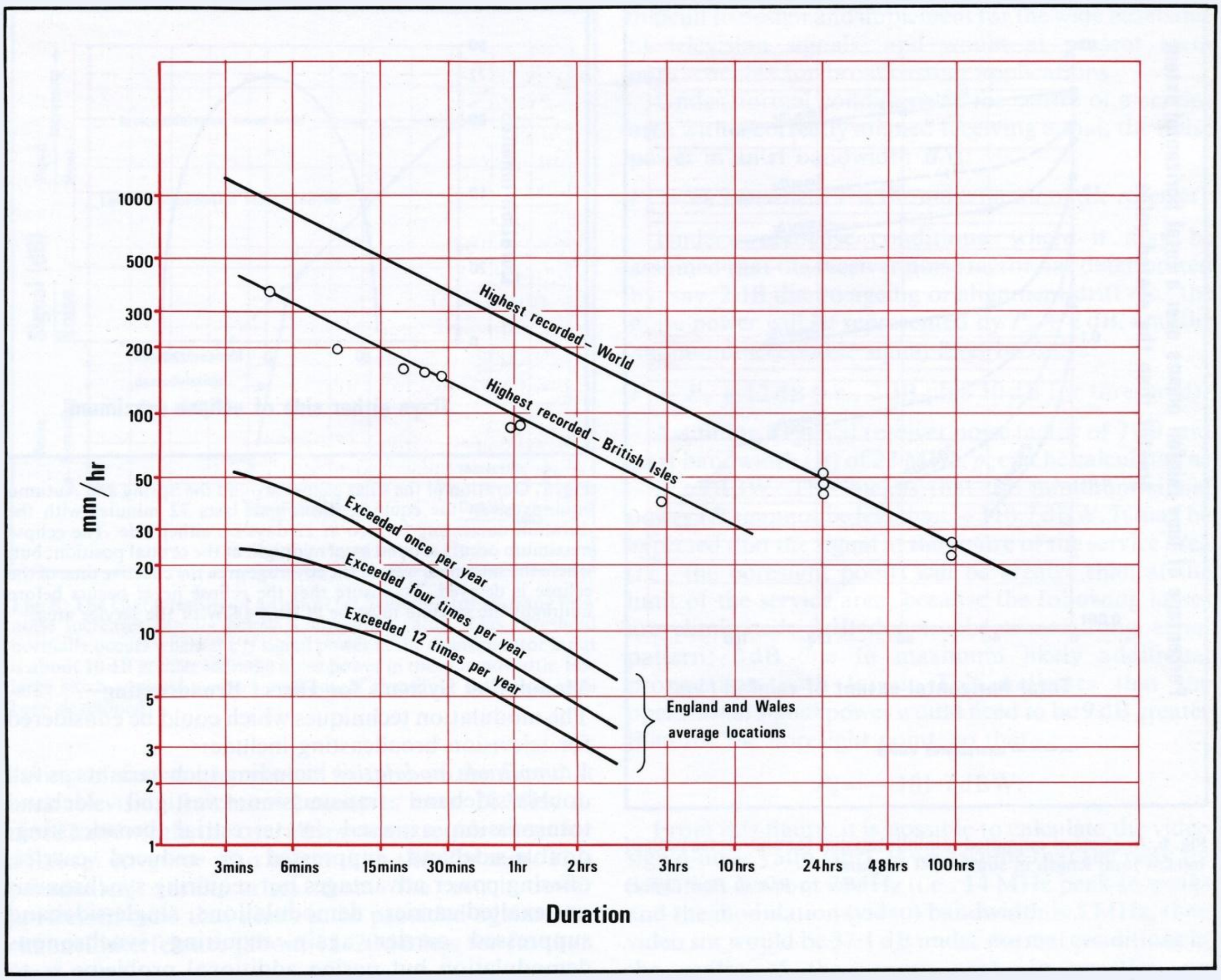


Fig. 5. The intensity of rainfall on the basis of duration and location. In some parts of the UK the figures will be appreciably higher than for the 'average' locations indicated, but are unlikely to exceed the 'highest recorded' intensities.

in the length of the solar day. When measuring time by clocks, it is more convenient to refer to mean solar time. At the equinoxes the difference between true and mean solar time is about 7 minutes, with the eclipse early at the Autumn equinox and late at the Spring equinox.

Taking into account the worst case (Autumn equinox), then in order to ensure that an eclipse never occurs before midnight in the coverage area, the satellite must be West of the service area by about $9° + 2° = 11°$.

Nevertheless, there are occasions when television broadcasting continues virtually throughout the night. In those circumstances the eclipse of solar cell arrays has considerable practical significance.

Orbital Errors

There is considerable scope for errors during the launching of satellites into geo-stationary orbit. If the radius of the final orbit were in error by only 70 ft (in 22 300 miles), the satellite would drift by 0·1°/year.

An orbit may not be quite circular—although of the correct period. This causes the bearing of a satellite to go through a cyclic variation as 'seen' from a point on Earth. If this variation is not to be more than ± 0·1° the radius must not fluctuate by more than ± 23 miles.

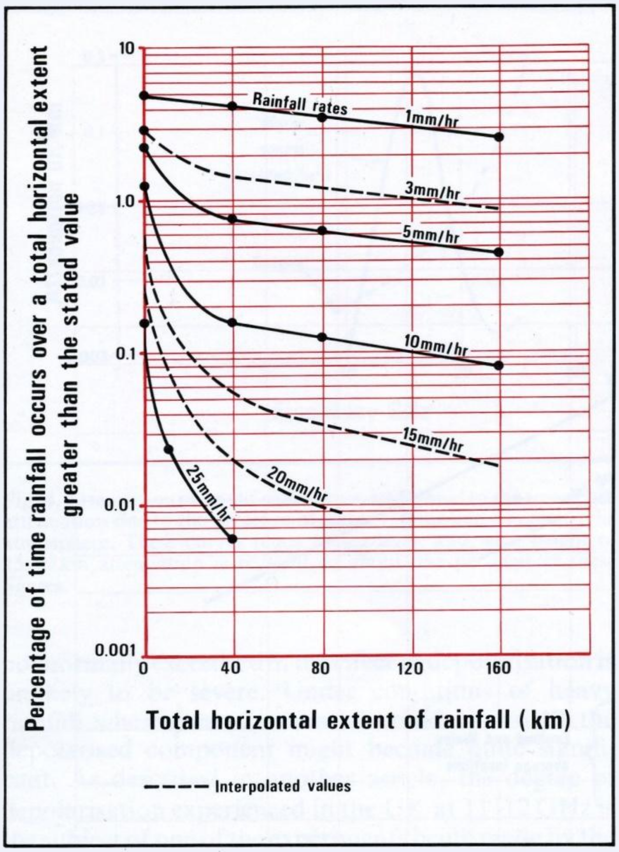


Fig. 6. Analysis of estimated rainfall statistics for an oversea path of 160 km total length in south-west England.
(due to British Post Office)

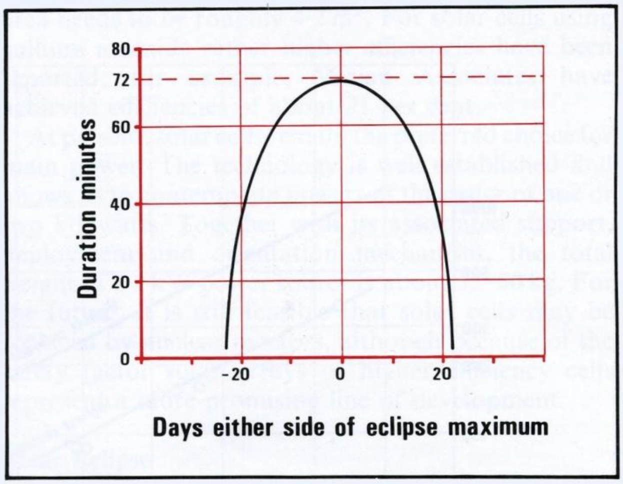


Fig. 7. Duration of the solar eclipse around the Spring and Autumn equinoxes. At the equinox the eclipse lasts 72 minutes with the duration decreasing to zero at 22 days on either side. The eclipse maximum occurs around local midnight at the orbital position; but, where the satellite is west of the coverage area the effective time of the eclipse is delayed. To ensure that the eclipse never occurs before midnight the satellite must be at least 11°W of the service area.

It should be noted that, with such a fluctuation, Doppler effect will cause a variation in received carrier frequency of some ± 110 Hz for a transmitter frequency of 12 GHz.

The launch precision and apogee motor precision achieved in practice are remarkable. However, in order to put the satellite into the correct position, and to keep it there, it is necessary to make provision for the use of small gas jets. This inevitably sets a limit to the operational life of the satellite, since it cannot be kept accurately on station after the fuel for these jets is finally exhausted. Clearly, the lifetime will be extended if the initial launch is of high accuracy, minimising the amount of correction needed to bring the satellite on-station. It is also important to note that, after launching, it will often take several weeks to bring the satellite accurately on station.

Modulation Systems for Direct Broadcasting

The modulation techniques which could be considered for television broadcasting include:

1. *amplitude modulation* including such variants as full double-sideband transmission; vestigial sideband transmission as used in terrestrial broadcasting; double-sideband suppressed or reduced carrier, offering power advantages but requiring synchronous or exalted-carrier demodulation; single-sideband suppressed carrier again requiring synchronous demodulation but posing additional problems as to providing the local reference carrier;
2. *frequency modulation* as used in conventional microwave links; such variants as single-sideband fm are technically feasible but unlikely to be seriously considered at present.
3. *digital modulation* systems (as discussed in another section) of which the most suitable variant would appear to be phase-shift keying.

The major factors are the limitations imposed on satellite transmission power by present primary power sources and the need to keep down the costs of domestic receivers.

A comparison between possible forms of a.m. and fm shows that the transmitter power for a.m. would need to be some 20 dB greater than for fm; at the present time this is a crucial factor.

The advantages of fm extend beyond that of the

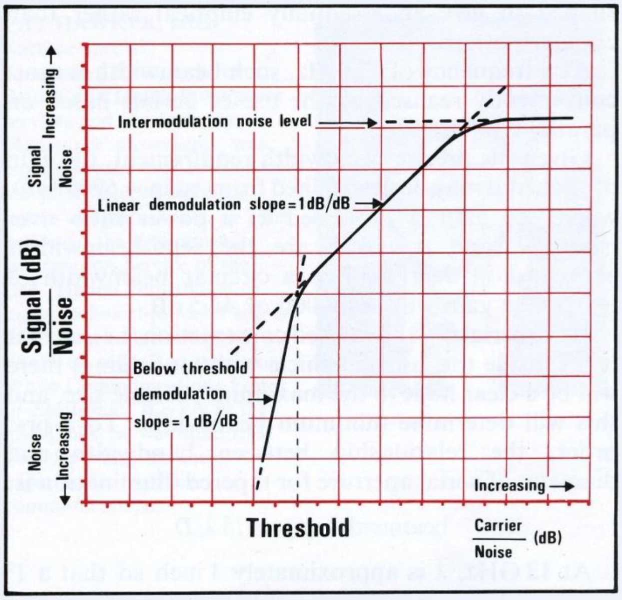


Fig. 8. The characteristic of a typical fm demodulator showing how noise increases rapidly below a threshold value. This threshold normally occurs where the rf signal power at the discriminator input is about 10 dB greater than the noise power in the rf bandwidth. For large earth stations various methods of threshold extension have been developed.

saving of transmitter power; in spite of the fact that each television fm channel occupies some 20 MHz or more bandwidth, the overall spectrum requirement for a full fm coverage plan is less than that for a.m. This paradoxical result arises from the much lower protection ratio that needs to be provided against co-channel interference (about 15–20 dB less for fm than for a.m.).

With fm, the essential point in providing service coverage is that the signal level cannot be allowed to fall below the so-called fm threshold level for the receiver; if this happens, there will be an extremely rapid increase in receiver noise and signal degradation. For conventional fm discriminators, this threshold normally occurs when the rf signal power at the discriminator input is about 10 dB greater than the noise power in the rf bandwidth. For specialist earth station terminals, various forms of 'threshold extension' have been developed. One method is that of compressing the spectrum of the i.f. signal into a narrower band prior to detection by the use of frequency-following techniques. An alternative approach is in the use of a phase-locked loop demodulator. Unfortunately, both these forms of threshold extension demodulators are extremely difficult to design and implement for the wide baseband of television signals, and would at present seem impracticable for broadcasting applications.

Under normal conditions at the centre of a service area with a correctly aligned receiving aerial, the noise power in an rf bandwidth B is:

$P_n = FkTB$ (where F is the noise factor of the receiver).

Under worst-case conditions, where it may be assumed that the receiver noise factor has deteriorated by, say, 2 dB due to ageing or alignment drift etc., the noise power will be represented by $P_n + 2$ dB, and the minimum acceptable signal level becomes:

$P_s = P_n + 12$ dB (i.e., 2 dB plus 10 dB for threshold).

Assuming a typical receiver noise factor of 7 dB and an rf bandwidth (B) of 27 MHz, p_n can be calculated as $-122{\cdot}7$ dBW. This means that the minimum signal power (P_s) cannot be less than $-110{\cdot}7$ dBW. It may be expected that the signal at the centre of the service area (i.e., the boresight point) will be greater than at the limit of the service area, because the following losses are eliminated: 3 dB due to the transmitting aerial pattern; 6 dB due to maximum likely additional propagation path losses. This indicates that the operational signal power would need to be 9 dB greater than for the boresight point, so that:

$$P_s = -101{\cdot}7 \text{ dBW}.$$

From this figure, it is possible to calculate the video signal/noise ratio (snr). If we assume that the peak fm deviation is about 7 MHz (i.e., 14 MHz peak-to-peak) and the modulation (video) bandwidth is 5 MHz, then video snr would be 37·1 dB under normal conditions in the centre of the service area. In practice, an improvement of about 2 dB could be achieved by the use of pre-emphasis/de-emphasis techniques, and a further safety margin would be added by slightly increasing the transmitter power to allow for operational variations in output power and other relatively small contingency factors.

Thus typically, under normal conditions in the centre of the service area, the receiver signal input power should be about -101 dBW and the corresponding video snr would be about 40 dB, or roughly equivalent to Grade 4·5 on the European Broadcasting Union five-point scale.

At the edges of the service area this will degrade by about 3 dB due to the transmitting aerial beamwidth, and there would be further loss in heavy rain etc., due to propagation losses. However, it is assumable that, at the edge of the service area, the video snr should not be

less than about 33 dB for 99 per cent of the time, corresponding to Grade 3·5.

Aerials for Satellite Broadcasting

It must be recognised that the correct alignment of receiving aerials may, in practice, prove one of the more critical areas of satellite broadcasting.

Clearly, the receiving aerial needs to be as large as practicable in order to reduce the need for high transmitter powers and high power flux densities which (some countries have suggested) might interfere with terrestrial systems. It is usual to assume that a receiving aerial of about 0·5 m^2 is permissible. This corresponds in practice to a square aperture having sides of length about 71 cm, or a circular aperture of diameter 80 cm. The resulting beamwidth at 12 GHz would be about 2·4° (beamwidth is approximately equal to $75\,\lambda/D(°)$ for circular aperture).

A beamwidth of 2·4° (±1·2°) corresponds to an aerial gain of 36·8 dB relative to isotropic.

The transmitting aerial must be capable of producing a beamwidth sufficient to cover the target country. This implies, for use in Europe, a beamwidth of the order of ±0·5°, although it may need to be shaped to give an essentially elliptical rather than circular pattern.

At a frequency of 12 GHz, such beamwidth is most conveniently realised by the use of aerials based on parabolic reflectors.

Given the precise beamwidth requirement, the gain of the aerial may be determined from: gain = $6900/(ab)$, where the gain is expressed as a power ratio over isotropic, and a and b are the semi-beamwidths expressed in degrees. For a circular beamwidth of ±0·5° the gain will be 28 000 or 44·5 dB.

If the aerial is to be of fixed construction (i.e., so that it fits inside the launch vehicle without folding) there will be a clear limit to the maximum possible size, and this will determine minimum beamwidth. To a first order, the relationship between bandwidth and diameter of aerial aperture for tapered illumination is:

$$\text{beamwidth } (°) = 75\,\lambda/D$$

At 12 GHz, λ is approximately 1 inch so that a 1° beamwidth requires a parabolic aerial with a diameter of about 6 ft. If a launch vehicle is able to accommodate an aerial of 10 ft diameter, the minimum beamwidth would become about 0·6° (±0·3°).

PAT HAWKER, after wartime special communications work for the British and Dutch Intelligence services and the European 'Resistance' movements, was engaged from 1947 to 1968 in the publishing of technical books and periodicals. In 1968 he joined the Engineering Information Service of the IBA. He has contributed to many technical journals and is the author of a number of books on radio and television. While Communications Editor of *Electronics Weekly* in the mid-1960s, he was concerned with reporting the early experiments in space communications.

Low-cost Satellite Receiving Techniques

by Pat Hawker

Synopsis

This article emphasises the importance of achieving low-cost receivers for direct satellite broadcasting. It explores the limiting factors of aerial gain and noise temperature and the specification of a figure-of-merit (G/T ratio). The practical problems of domestic receiving aerials include not only size and profile accuracy but also the equally important question of accurately installed systems for mass audiences. The main problem in a receiver design is that of the 'front end' and the transition of microwave mixers and sources from high cost precision components to the domestic environment. A low-cost design proposed by NHK Japan is outlined; the feasibility of using harmonic mixers by means of anti-parallel diodes is explored; and the question of receive filters is discussed. Although uhf broadcasting from satellites is unlikely in Europe, that may not be so in other parts of the World, and some comments on this are included.

For any new system of broadcasting to succeed, it is a basic requirement that high-cost elements should be confined to the broadcaster rather than distributed among millions of receiving installations. For direct broadcasting from satellites to succeed, the picture in the home must be of good quality, and must relate to the costs of conventional terrestrial broadcasting reception, including receiver and aerial costs and installation and maintenance charges.

Set-makers have in the past coped effectively with the repeated demand by the frequency spectrum planners to use higher and even-higher frequencies. Radio broadcasting began around 1 MHz; soon involved 'Empire' services between 6–16 MHz; early high-definition television called for 40 MHz reception; the coming of Independent Television (ITV) in 1955 in Band III put television in the region of 200 MHz; while the 625-line UK colour services have raised the limit to 470–850 MHz. Yet, never before has a single increase spanned so many octaves as would the introduction of 12 GHz satellite television.

Furthermore, the World Agreement has placed an unexpectedly severe limit on permissible power flux. At $-103\,\mathrm{dBW/m^2}$ this is some 2 dB lower than had been widely expected, and very much lower than the early visionaries had assumed.

Indeed, the 'down-link' (satellite–earth) is significantly more demanding in its requirements for good receiving installations than is the 'up-link' (earth-satellite) where cost is of far less importance.

The limiting factors in satellite reception are the aerial gain and thermal noise (noise temperature) of the receiver. Both the net gain of an aerial and the noise temperature of the system are usually referred to, or measured at, the input to the receiver. It must be appreciated that the aerial receives unwanted noise energy from the sky and that this increases rapidly at low angles of elevation. Ideally, the first stages of a receiver should have not only a low noise temperature (often defined in terms of noise factor) but also sufficient gain to reduce to an insignificant value the noise contributions of succeeding stages.

For the receiver designer, a significant advantage of space broadcasting would be the relative uniformity of signal strength; generally there would be much less variation than is common with terrestrial vhf/uhf networks. If all broadcasts on Band VI were transmitted from space, the dynamic range of the receiver could be relatively small. There would also be fewer 'multipath' problems.

G/T Requirements

The performance of a satellite receiving installation is often specified by the gain-to-noise temperature ratio (G/T) with both factors referred to the input of the receiver. Since T is a function of elevation angle of the aerial and G is a function of the frequency, both should be specified or clearly understood when considering a G/T figure-of-merit. The figure-of-merit may clearly be held to be a specific figure for a higher system noise temperature by increasing the gain of the aerial; or, for a lower gain aerial, by reducing the system noise temperature.

It may be noted that the original Intelsat specification for earth stations costing in the region of £1-million or more required the following performance:

$$G/T \geq 40{\cdot}7 + 20\log_{10}f/4$$

and

$$G \geq 57 + 20\log_{10}f/4$$

In the 4 GHz band this implied that, with an aerial net gain of 57·7 dB (which could be achieved with a parabolic aerial of 85 ft diameter) the earth station noise temperature of the receiver would not exceed 50°K. Of this 50°K, possibly 20°K might be contributed by a cooled parametric amplifier and up to 30°K by the aerial at the working elevation. It will be appreciated that such performance was close to the 'state-of-the-art' in the 1965–70 era, and parabolic aerials of about 100 ft diameter were commonly used.

12 GHz Aerials

Such high G/T ratios are unnecessary for domestic and/or community reception. For the 11·7–12·5 GHz band with a power flux of $-103\,\mathrm{dBW/m^2}$ a G/T of 6 dB (K^{-1}) will provide satisfactory colour television pictures at the outer edges of the service area.

This suggests that an aerial with a parabolic reflector of slightly less than 1 m diameter would be required with a receiver noise factor of about 8 dB. Within the United Kingdom arrival angles of a signal from a satellite positioned at 31°W would vary from about 27° in the south-west of England to about 17° in the Shetland Islands.

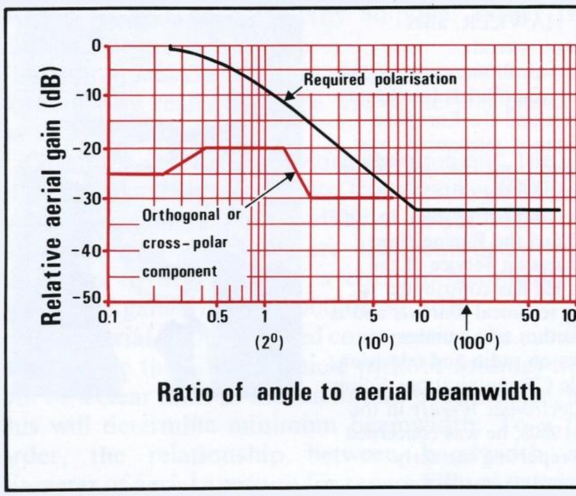


Fig. 1. The CCIR template showing the reference patterns for minimum directivity characteristics of domestic/community receiving aerials for satellite broadcasting. Maximum discrimination against the cross-polar component is required at the centre of the beam where an aerial gain of some 33 dB is specified.

The effective gain of a parabolic aerial depends upon the profile accuracy of the paraboloid; in practice, it is usually accepted that there can be departures of up to one-tenth wavelength without significant deterioration of gain and directivity. However, at 12 GHz a wavelength is only 0·025 m; so, the profile tolerance is preferably of the order of $\pm 0{\cdot}0025$ m or better from true paraboloid—a figure demanding care in construction and installation, and protection of the surface skin against deformation and pitting during its useful life.

The receiving aerial also needs to be pointed towards the satellite with an accuracy better than 0·5°. When this figure is related to an average domestic uhf aerial it will be appreciated that installations will require a high degree of care. Fortunately, however, provided that a means of adjustment is provided, it should prove possible to line-up an aerial by observing the picture, rather than by dead reckoning. The waveguide feed for a small parabolic aerial is complicated by the decision to use circular polarisation. However it will not be necessary to seek 'height-gain' for satellite receiving aerials; and typically, an installation could be wall-mounted, and with a fairly simple provision for fine adjustment.

With an elevation of 24° in the London area, it should not be difficult to achieve a clear 'line-of-sight' towards the distant satellite; though lower apartments in any heavily built-up area might in a few cases present problems. The surface of a metallised parabolic aerial

in an urban or coastal environment will almost certainly require protection, but it has been suggested that, for example, the paraboloid might be enclosed in polythene sheeting which could be renewed when necessary.

No matter how effectively the receiving aerial may have been designed, or how carefully it may have been packed and transported, the long-term performance will depend on the care with which it is installed. The construction and mounting must be capable of withstanding the effects of wind and weather, including any possible warping or structural changes throughout the estimated operational life.

The 'view' of the satellite must be unobstructed; while there will be few places in the UK where the natural topography is likely to cause screening, this may be a serious problem among large buildings or tall trees. Even where the power flux density is sufficient to permit the use of individual aerials, there will clearly be advantages in providing community systems, each with one master aerial and with associated front-end serving a number of installations. Distribution could be at the video baseband, hf/a.m., vhf/a.m., or uhf/a.m. or 1·2 GHz/fm, etc.

The economics of the mass-market make it essential that the manufacture of any consumer aerial should be easy and straightforward. Aerials should be designed for easy packing; transporting; be marketable at reasonable price; be suitable for assembly, erection and alignment by a rigger to a time-scale of the order of 30–60 minutes; offer low resistance to winds; and perform without excessive degradation in the presence of snow or ice. It is likely that the cost of installing a small parabolic aerial (0·6–1 m diameter) of effective performance at 12 GHz would be several times that of a conventional service-area uhf receiving aerial. Also, of the two, the paraboloid might deteriorate the more rapidly.

12 GHz Front-ends

The development (for other applications) of effective microwave solid-state techniques which appear to lend themselves reasonably well to quantity production techniques, makes it possible to contemplate with some confidence a generation of 12 GHz receivers. Perhaps the most daunting requirement is a low-cost reasonably stable and spectrally pure microwave 'source' to provide the local oscillator. Fortunately, in the early 1960s, the British scientist J B Gunn discovered that certain diodes can be caused to oscillate at shf. The stability of these can be improved with a high-Q cavity. More recently, progress has been made in the development of microwave transistors, such as the gallium arsenide (GaAs) field-effect devices.

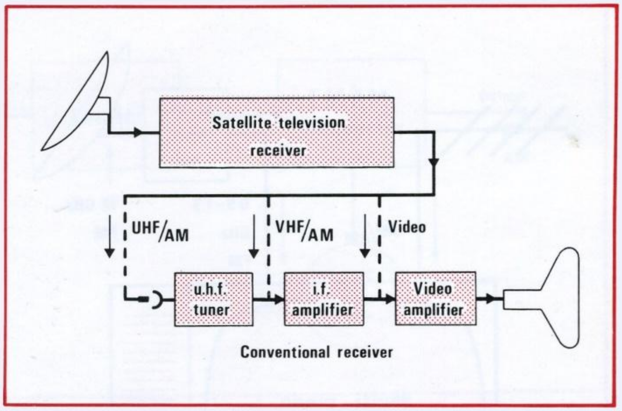


Fig. 2. There are a number of basic receiver configurations which could be adapted to interconnect a 12 GHz fm receiver/adaptor with a conventional uhf/a.m. receiver. An adaptor providing a uhf/a.m. output could be connected directly to the aerial socket of an existing receiver. Alternatively, an output at the i.f. of the main receiver could feed into the i.f. amplifier section. Output at video frequency would be attractive in reducing spurious signals but would require the provision of an 'isolated' socket, possibly using an optical coupling arrangement.

For a 12 GHz 'front-end' adaptor the power output of the local oscillator needs to be only a few milliwatts but, unless automatic frequency correction is employed, the frequency must be stable within about ±0·1 MHz.

The UK has been assigned channels 4, 8, 12, 16 and 20; so, a tunable converter would need to cover a tuning range of some 400 MHz. However, it is likely that the microwave oscillator would be fixed in frequency; channel selection would be achieved by varying the first intermediate frequency with afc applied to the second oscillator. It has been suggested that the first i.f. for a 12 GHz satellite receiver would be in the region of 1200 MHz and a second i.f. about 140 MHz. Both these frequencies are close to amateur service allocations (with high local field strengths in residential areas). Gunn diodes could be manufactured economically in large quantities, also low-cost forms of high-*Q* cavities would seem feasible. An alternative approach would be to use a crystal-controlled chain, or, rather more promising (since higher fundamental frequencies are possible), a surface acoustic wave oscillator. If the cost of Varactor diode multipliers, step-recovery diodes and microwave GaAs field-effect-transistors fall, it may become possible to produce relatively stable microwave sources within the cost-range of consumer equipment.

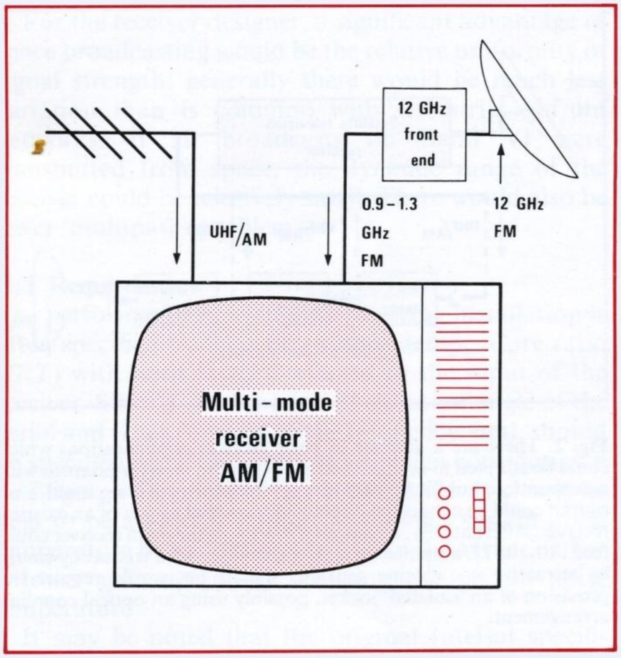


Fig. 3. The development of multi-mode television receivers, capable of accepting an fm signal between, say, 0·9–1·3 GHz would provide one of the more attractive configurations for domestic satellite receivers.

Until recently the possibility of providing an effective 12 GHz low-noise signal amplifier at acceptable consumer prices would have seemed remote, and most tentative designs have been based on feeding the signal directly to a diode mixer, with the object of achieving an overall noise figure of 6–8 dB. However, continuing advance in bipolar and field-effect microwave transistors no longer rules out the possibility of a signal frequency amplifier, reducing the noise figure to perhaps 4–6 dB. It is notable that, in less than a decade, estimates of 12 GHz noise figures have dropped from about 12 dB to about 7 dB. The constructional technique based on a single planar metallic sheet with suitable simple cut-outs, etc., would appear to present few problems to mass-production. Such approaches would enable quantity-production of 12 GHz converters which could be attached directly to the aerial feed waveguide; such method would appear to make possible a G/T figure-of-merit better than 7 dB, with sufficient 'image rejection' etc., and would leave a small margin for deterioration or less-than-precise installation.

The power levels of satellite transmission currently make frequency-modulation a virtual necessity; the satellite adaptor would need to provide an output either at video frequency or as an amplitude-modulated uhf signal, or be incorporated in a complete multi-mode receiver. In practice it seems more likely that a special a.m./fm television receiver would be developed which would accept a.m. signals at Bands IV and V (and possibly Bands I and III) and fm signals from the 12 GHz converter over the range 0·9–1·3 GHz. Many configurations for domestic or small community distribution systems are possible.

NHK 12 GHz FM Receiver

One of the most interesting designs for a 12 GHz fm receiver yet to appear stems from the NHK Technical Research Laboratories in Japan. This provides a high-sensitivity microwave receiver using circuit and constructional techniques which make it attractive for quantity production at low cost: Fig. 4. The 12 GHz converter uses a planar circuit mounted in a short section of waveguide with all circuit elements made by pressing or etching, so eliminating the need for precision machine processing. It is claimed to result in a down-converter with a Q value several times that of a filter in a conventional microwave integrated circuit. The metal sheet can be of the order of 0·3 to 0·5 mm in thickness. The Schottky mixer diode serves as the impedance matching between high-impedance waveguide and the diode which is directly mounted on the planar circuit. A Gunn diode is used as the local oscillator.

This receiver also incorporates a low-cost fm/a.m. converter to allow the 430 MHz output to be fed directly to the aerial socket of a uhf a.m. receiver without any video and sound amplifier and modulator. In effect, this fm/a.m. converter uses the non-linear characteristic of the mixer diode to produce amplitude variation of the output signal proportional to the fm deviation of the input signal.

A laboratory unit has a claimed noise figure of 4·5 dB, conversion loss of 3·4 dB, bandwidth of 100 MHz, differential gain 5 per cent or below, and differential phase of 2° or less. The achievement of such a low noise figure without an shf amplifier is remarkable.

MRL Satellite Receiver

A design developed at the Mullard Research Laboratories (now known as Philips Research Laboratories) in conjunction with Philips, Eindhoven, adapted for 525-line NTSC system, was one of a number of models demonstrated with the CTS 'Hermes' satellite tests during 1976. These receivers used 1·6 or 1·2 m parabolic aerials of metal-coated

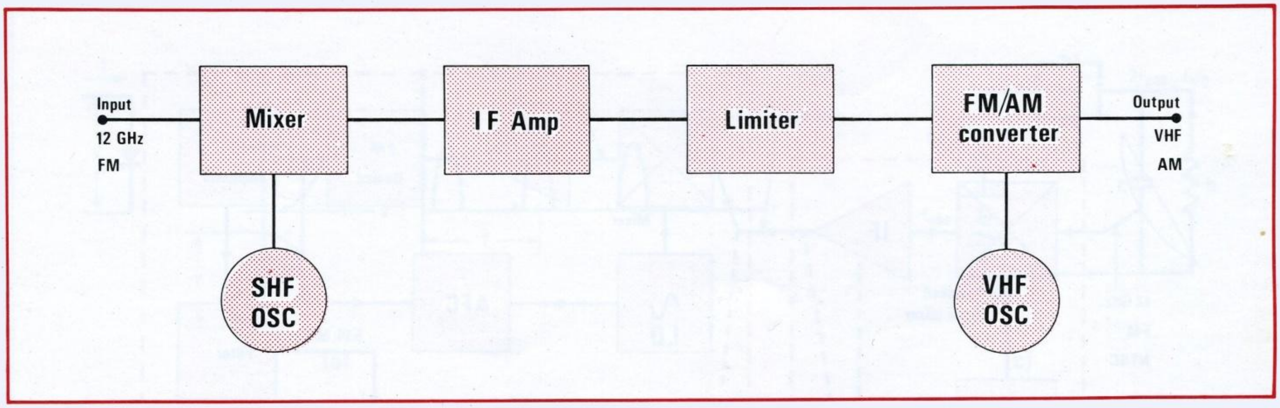


Fig. 4. Block outline of the experimental NHK 12 GHz satellite front-end developed with a view to providing a low-cost approach. The 12 GHz converter, using a Schottky diode mixer and Gunn diode oscillator, has a planar circuit mounted in a short section of waveguide with all circuit elements fabricated by pressing or etching, and with no precision machine processing. A very simple form of fm/a.m. conversion provides an output at vhf.

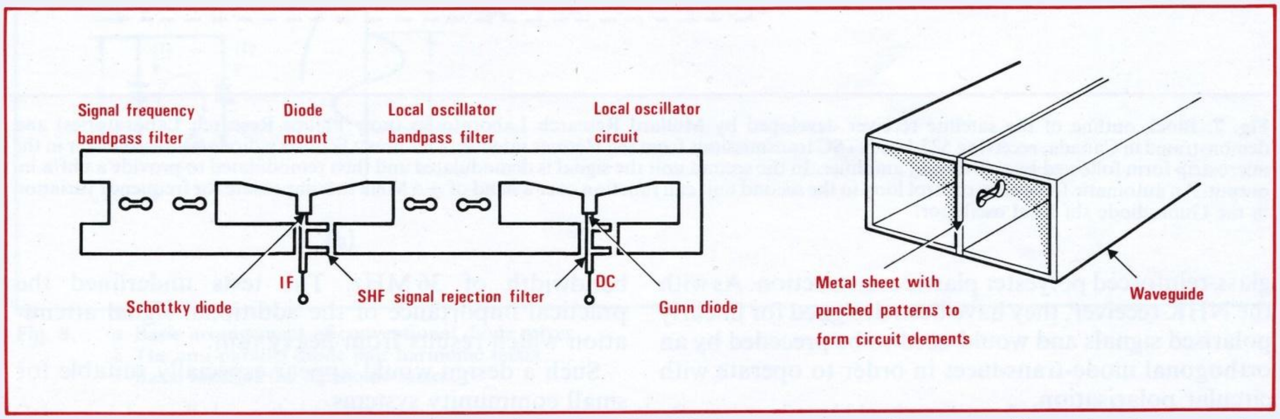


Fig. 5. Details of the 12 GHz converter with planar circuit developed by NHK for an experimental low-cost satellite receiver. In essence it is a metal sheet with patterns punched-out to form circuit elements. A laboratory unit has a claimed noise figure of 4·5 dB and conversion loss of 3·4 dB.

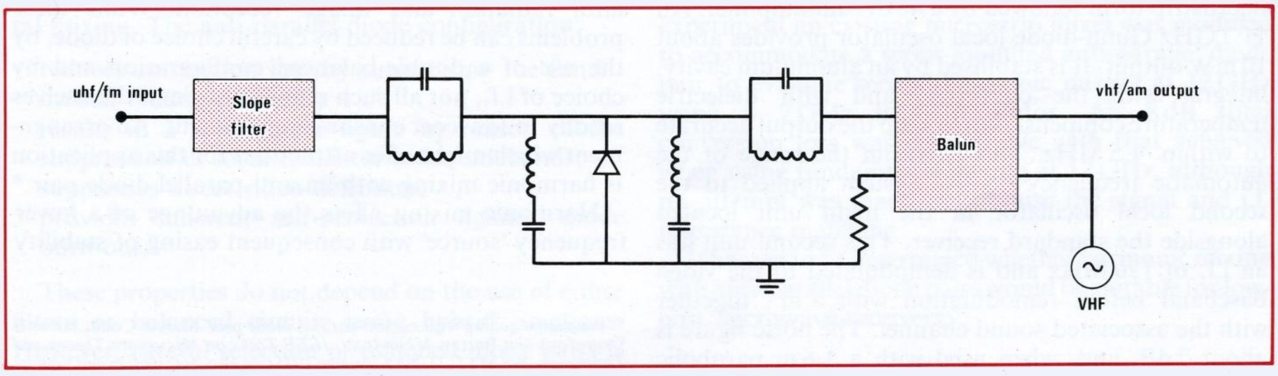


Fig. 6. Circuit diagram of the simple form fm/a.m. converter used in the experimental NHK low-cost design. This provides a vhf/a.m. output suitable for use with a conventional television receiver.

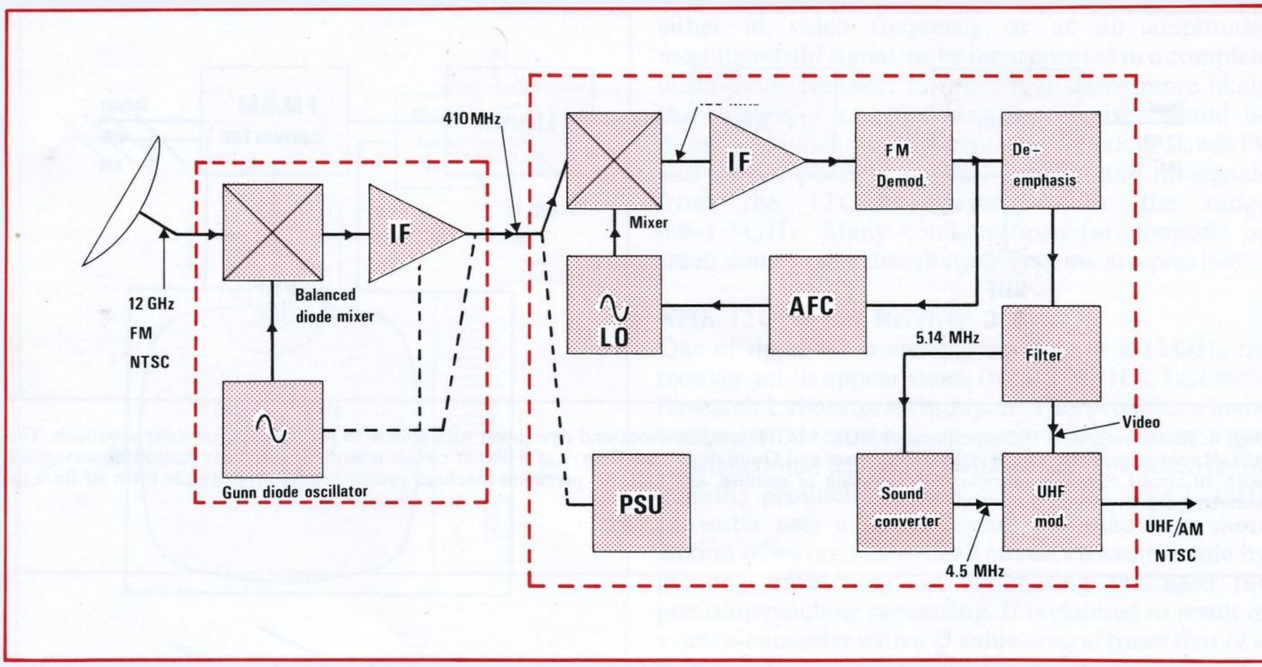


Fig. 7. Block outline of the satellite receiver developed by Mullard Research Laboratories (now Philips Research Laboratories) and demonstrated in Canada, receiving 525-line NTSC transmissions from the Hermes satellite. This uses a Schottky-diode balanced mixer in the microstrip form followed by a 40 dB uhf amplifier. In the second unit the signal is demodulated and then remodulated to provide a uhf/a.m. output. An automatic frequency control loop in the second unit can function over a band of ±5 MHz to compensate for frequency variation in the Gunn diode shf local oscillator.

glass-reinforced polyester plastic construction. As with the NHK receiver, they have been designed for linearly polarised signals and would need to be preceded by an orthogonal mode-transducer in order to operate with circular polarisation.

Figure 7 shows the basic arrangement of the MRL converter. To frequency-change from 12 GHz to 410 MHz a microwave unit, mounted close to the aerial, uses a Schottky-diode balanced mixer in microstrip form followed by a 40 dB uhf amplifier. An 11·7 GHz Gunn-diode local oscillator provides about 10 mW output. It is stabilised by an aluminium cavity, integral with the converter, and with dielectric temperature compensation to keep the output accurate to within ±5 MHz. This is within the range of the automatic frequency control system applied to the second local oscillator in the main unit located alongside the standard receiver. This second unit has an i.f. of 120 MHz and is demodulated to the video baseband before remodulation with a.m., together with the associated sound channel. The noise figure is about 7 dB, and, when used with a 1·6 m parabolic aerial (43 dB gain), can provide good reception from a received signal of about −105·5 dBW with a receiver bandwidth of 36 MHz. The tests underlined the practical importance of the additional signal attenuation which results from heavy rain.

Such a design would appear especially suitable for small community systems.

Harmonic Mixing

The problems presented by a simple diode mixer include the unavoidable conversion loss, local oscillator radiation and 'image' reception. While these problems can be reduced by careful choice of diode, by the use of a double-balanced configuration and by choice of i.f., not all such refinements lend themselves readily to low-cost consumer equipment. An arrangement which might offer attractions for this application is harmonic mixing with an anti-parallel diode pair.*

Harmonic mixing offers the advantage of a lower frequency 'source' with consequent easing of stability

* 'Harmonic mixing with an anti-parallel diode pair' Marvin Cohn, James E Degenford and Burton A Newman, *IEEE Trans on Microwave Theory and Techniques*, Vol MTT-23, No 8, August 1975 (see also *Automation and Remote Control* (USSR) Vol 19, April 1958, pp. 355 *et seq.; IRE Trans on Instrumentation*, Vol 1–9, No. 3, December 1960, pp. 349–355 *IEEE Trans MTT*, March 1975; *IEEE Trans MTT*, May 1976).

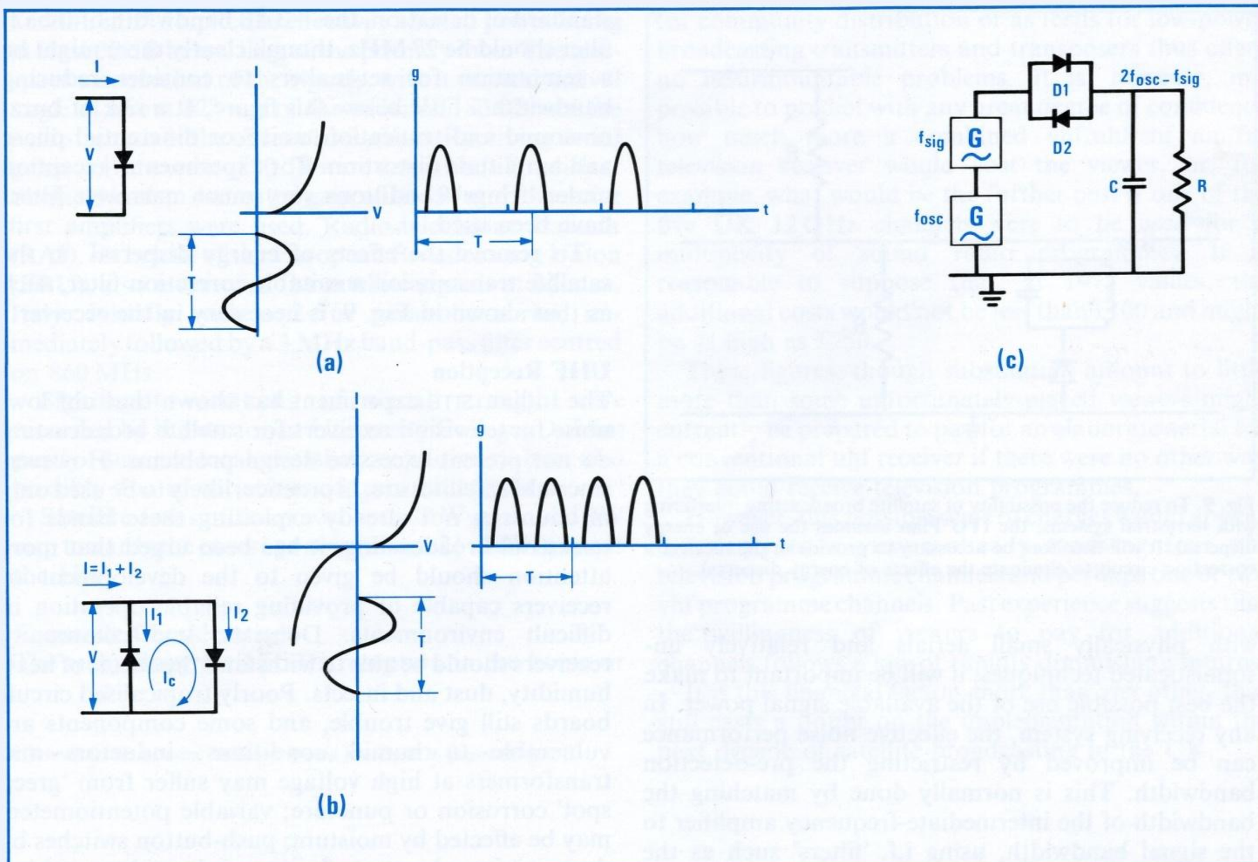


Fig. 8. *a* Basic arrangement of conventional diode mixer.
b The anti-parallel diode pair harmonic mixer.
c Basic form of the harmonic mixer.

Cohn *et al.* have all shown that harmonic mixing not only reduces the frequency of an shf local oscillator, but also reduces the effect of oscillator noise side-bands and provides inherent self-protection against diode burn-out. However, careful selection of diode pairs is needed to obtain the full benefits. Total conversion loss can be comparable to that achieved with similar diodes with fundamental mixing.

problems. However, in most arrangements it results in conversion loss 3–5 dB greater than that of fundamental mixing. The anti-parallel diode configuration:

- reduces conversion loss by suppressing the fundamental mixing products;
- results in a lower noise figure by reason of the suppression of local oscillator noise sidebands;
- suppresses direct video detection;
- provides inherent self-protection against diode burn-out.

These properties do not depend on the use of either filters or balanced circuits using hybrid junctions. However, careful selection of matched diode pairs is necessary to obtain the full advantages. Experimental harmonic mixers, reported by Cohn, Degenford and Newman have used a pair of GaAs Schottky barrier diodes shunt-mounted across a slot line. In one experiment an existing microstrip mixer was modified to accommodate a series-mounted anti-parallel diode pair to evaluate second-harmonic mixing at 12 GHz using a 7 GHz local oscillator. An 8 dB total conversion loss was comparable with that achieved when using fundamental mixing at 12 GHz, although no attempt was made to optimise the signal and i.f. impedance matching.

It has yet to be determined whether harmonic mixing with anti-parallel diode pairs would be suitable for low-cost microwave receivers.

Receive Filters

Since a low-cost satellite receiver will require to operate

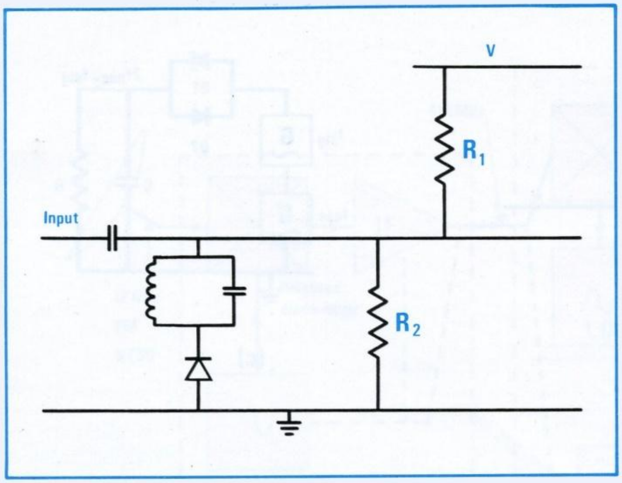


Fig. 9. To reduce the possibility of satellite broadcasting interfering with terrestrial systems, the ITU Plan assumes the use of energy dispersal. It will therefore be necessary to provide in the receiver a correction circuit to eliminate the effects of energy dispersal.

with physically small aerials and relatively unsophisticated techniques, it will be important to make the best possible use of the available signal power. In any receiving system, the effective noise performance can be improved by restricting the pre-detection bandwidth. This is normally done by matching the bandwidth of the intermediate-frequency amplifier to the signal bandwidth, using i.f. 'filters' such as the familiar single or double-tuned i.f. transformer or, its modern equivalent, the surface-acoustic-wave filter.

With frequency modulation there is no simple definition of the bandwidth, since, theoretically, the sidebands extend to infinity. Thus, any bandwidth restriction involves some loss of higher-order sidebands, and so introduces a degree of non-linear distortion. The practical effects of such non-linearity are more noticeable in systems employing a sub-carrier for the transmission of the sound channel.*

A N Kent shows that, while bandwidth reductions may be expected to improve the received carrier-to-noise ratio in a satellite receiver, if the spectrum of the modulated carrier is restricted unduly, truncation gives rise to signal distortion. The first subjective indication of this is usually buzz-on-sound, although a visible beat pattern between sound and chrominance subcarriers is also possible.

It has been suggested that, for the proposed UK standard of deviation, the −3 dB bandwidth of the i.f. filter should be 27 MHz, though clearly there might be a temptation for set-makers to consider reducing bandwidth a little below this figure, at a risk of buzz-on-sound and truncation 'noise' or differential phase and amplitude distortion. For experimental reception under 'fringe' conditions very much narrower filters have been used.

To remove the effects of energy dispersal on the satellite transmission a suitable correction filter, such as that shown in Fig. 9, is necessary in the receiver.

UHF Reception

The Indian SITE experiment has shown that uhf low-noise fm television receivers for satellite broadcasting do not present excessive design problems. However, since uhf satellites are, in practice, likely to be used only in countries not already exploiting these bands for terrestrial broadcasting, it has been urged that more attention should be given to the development of receivers capable of providing reliable operation in difficult environments. Domestic and community receivers should be able to withstand the effects of heat, humidity, dust and insects. Poorly tropicalised circuit boards still give trouble, and some components are vulnerable to humid conditions; inductors and transformers at high voltage may suffer from 'green spot' corrosion or puncture; variable potentiometers may be affected by moisture; push-button switches by dust; springs by rust, heat and humidity; rubber deteriorates rapidly. Unnecessary circuit complexity invites maintenance problems; equipment needs to be accompanied by instruction and servicing manuals produced in each appropriate language.

UHF reception has the advantage of established low-cost low-noise receiving techniques; however, it has the disadvantage that much larger aerial structures are required to obtain gains in excess of 20–25 dB. For the SITE experiment, aerials with 3 m diameter parabolic reflectors were used, constructed from expanded aluminium with a helical feed. Behind each aerial was a 'head-end' unit providing an i.f. output at 70 MHz. A second 'tail-end' converter was used to demodulate the 70 MHz fm signals to provide a video feed to the 22-in black-and-white receivers used in the Indian villages. The resulting video snr of about 45 dB resulted in good subjective picture quality. The 3 m uhf parabolic aerials represented no major problem for community receivers but would be regarded as too large for domestic installations.

During the SITE experiments, successful reception of the 860 MHz fm signals was reported from Sheffield

* A N Kent, 'Bandwidth optimisation in a direct satellite television broadcasting system'. *IEE Conference Publication* No 119.

and Dublin* despite the effective radiated power being at least 30 dB below that of the primary lobe. The free-space attenuation of the signals, with a vertical arrival angle of about 22° was of the order of 183 dB and the field strength of the order of 3·3 μV/m. Receiving aerial gains well in excess of 20 dB were desirable (a 5 ft dish at Sheffield had an estimated gain of 19 dB) and low-noise first amplifiers were used. Radio-televisione Italiana (RAI), on behalf of the European Broadcasting Union (EBU), also monitored the satellite signals at Monza, Italy, initially with a 2·5 m parabolic aerial, immediately followed by a 3 MHz band-pass filter centred on 860 MHz.

Significant variations of signal strength were recorded by the station at University College, Dublin; partly due to local weather conditions, but also possibly due to variations of transmitter power.

Satellite transmitter power was 80 W with 51 dBW eirp towards the coverage area (about 21 dBW towards the UK).

Economic Considerations

The technology for 12 GHz reception in the home or for community distribution or as feeds for low-power broadcasting transmitters and transposers thus offers no insurmountable problems. It is, however, impossible to predict with any great degree of confidence how much more a combined vhf/uhf/shf am/fm television receiver would cost the viewer, or, for example, what would be the further cost if one of the five UK 12 GHz channels were to be used for a multiplicity of sound radio programmes. It is reasonable to suppose that, at 1977 values, the additional costs would not be less than £100 and might be as high as £250.

These figures, though substantial, amount to little more than some unfortunately-placed viewers might currently be prepared to pay for an elaborate aerial for a conventional uhf receiver if there were no other way they could receive television programmes.

However, this possible scale of charges would appear differently to a viewer already receiving four uhf television programme channels and perhaps one or two vhf programme channels. Past experience suggests that the willingness of viewers to pay for additional channels follows a law of rapidly diminishing returns.

It is this financial factor, more than any other, that still casts a doubt on the implementation within the next decade of satellite broadcasting in the UK.

* Television from India, *Wireless World* March 1976 pages 68–70.

HUGH O'NEILL obtained a BSc(Eng) degree in Telecommunications and PhD in Microwave Engineering at University College, London. Subsequently he worked on the design of electronic warfare and radar systems for GEC Ltd before, in 1968, joining the IBA. He is currently a senior engineer in the Radio Frequency Section of the Experimental and Development Department of the IBA at Crawley Court. Recently he has devoted his spare time to reading for an Arts degree of the Open University.

DAVID GRIFFITHS, CEng, MIEE, joined the BBC in 1966 as a graduate trainee at the Daventry transmitting station. After a brief period investigating compact uhf transmitting aerials he joined the Studio Planning and Installation Department to work on the provision of video tape recording facilities at the BBC Television Centre. In 1968 he transferred to the Transmitter Planning and Installation Department, working on microwave link systems for television and stereo radio. He joined the IBA in 1975 as a senior engineer in the Network and Planning Department.

IBA Earth Station at Crawley Court

by H J O'Neill and D C Griffiths

SYNOPSIS
The IBA has built at its Engineering Centre, Crawley Court, near Winchester, an experimental 12 GHz satellite receiving system with a 3 m parabolic aerial. This has been specially equipped to enable IBA engineers to obtain detailed propagation data on cross-polarisation effects and to assess the performance likely to be achieved from an operational satellite system. A detailed description is given of the installation and the way in which cross-polarisation propagation and television performance can be monitored.

The first European communications satellite, OTS ('Orbital Test Satellite'), will make use of the 11 and 14 GHz telecommunications satellite bands. The launching of this experimental satellite, forerunner of the first operational European system ('European Communications Satellite' or ECS), offers broadcasters in Europe an opportunity of working with satellites and of gathering experimental data on shf propagation and satellite transmission performance. The IBA has assembled a small earth station to participate fully in some of the experiments to be carried out with OTS by members of the European Broadcasting Union (EBU). Initially, it has been used to receive 11·596 GHz beacon transmissions from the Italian SIRIO satellite.

The OTS is primarily intended to satisfy the requirement for inter-European public telecommunications traffic and for the exchange of television programmes through Eurovision. This traffic will normally take place through the very large earth stations belonging to the PTT administrations of the various countries concerned. OTS is also carrying various beacon transmitters so that shf propagation along both up and down paths can be studied. It is possible to receive these shf beacon signals on relatively small aerials. Direct reception of television signals by

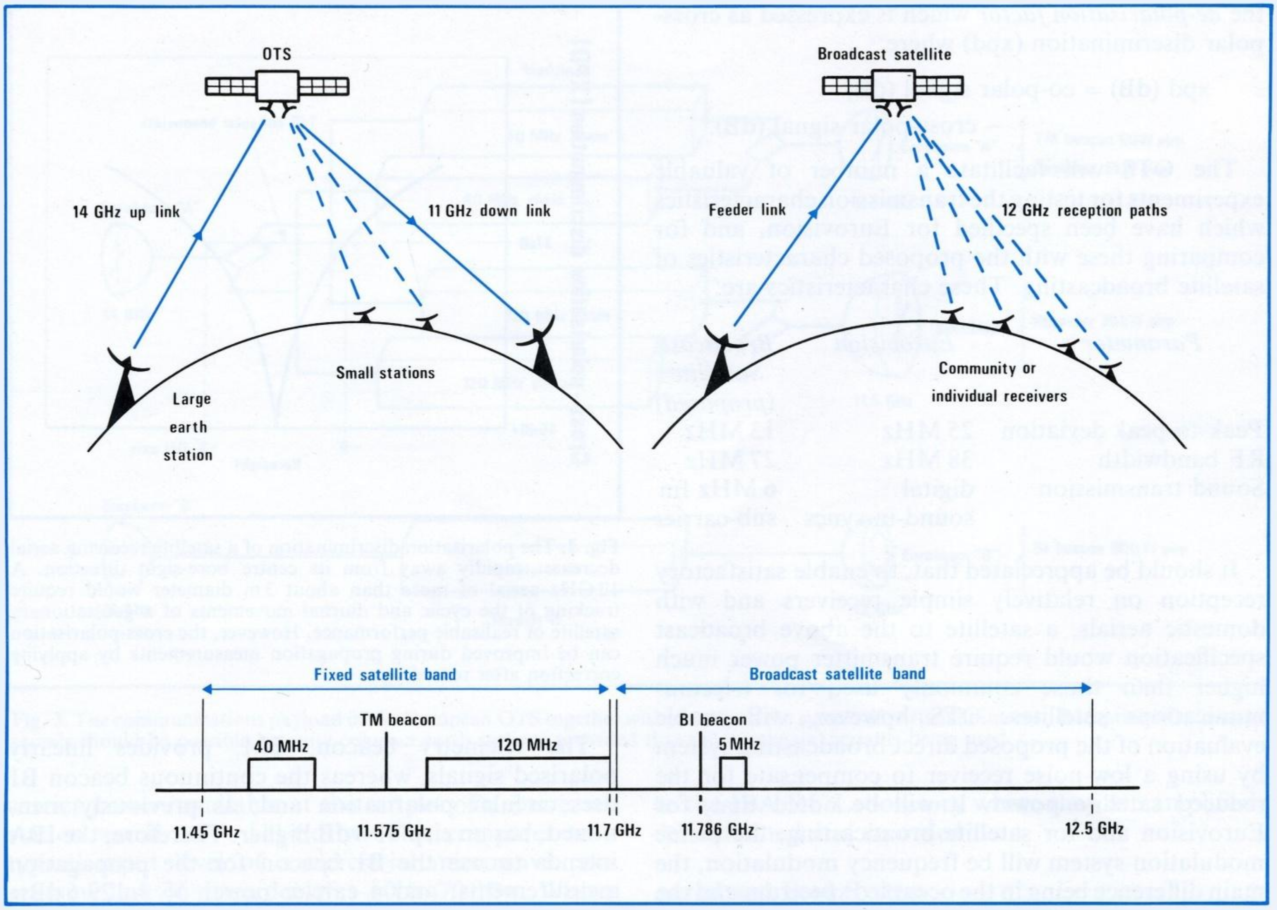


Fig. 1. Although the first European communications satellite, OTS, will use the telecommunications satellite frequency allocations 11 and 14 GHz, these straddle the 12 GHz broadcast allocation and enable the making of useful studies applicable to the satellite distribution system planned for Eurovision and to future direct broadcasting satellites. OTS will also carry a B1 continuous beacon transmitter at 11·786 GHz within the broadcast band.

compact earth stations is also possible, provided that the 'spotbeam' satellite aerial is being used for transmission.

The EBU have arranged with the European Space Agency, and with the PTT administrations concerned, that a series of broadcasting experiments shall be conducted through OTS, with the up-path provided by the large PTT earth stations.

The IBA 'receive-only' earth station uses a 3 m diameter parabolic aerial. It is fully equipped to receive the beacon signals radiated by the satellite for shf propagation studies and the television signals for the various broadcasting tests and measurements. It will enable IBA engineers to:

1. gain experience of working with satellites;
2. obtain propagation data for the space-earth path at frequencies around 12 GHz;
3. assess the performance to be expected from any future broadcasting satellite system;
4. assess the transmission performance of alternative modulation systems, using both analogue and digital modulation, and to evaluate techniques for improving the quality of reception (for example, the use of threshold extension demodulators).

Two parameters affected by the propagation path are of particular interest to broadcasters; these are the measurement of *excess attenuation* which is defined as the amount by which the clear sky (free-space) value is exceeded (and for how long); and the measurement of

the *de-polarisation factor* which is expressed as cross-polar discrimination (xpd) where:

$$\text{xpd (dB)} = \text{co-polar signal (dB)} - \text{cross-polar signal (dB)}.$$

The OTS will facilitate a number of valuable experiments for testing the transmission characteristics which have been specified for Eurovision, and for comparing these with the proposed characteristics of satellite broadcasting. These characteristics are:

Parameter	*Eurovision*	*Broadcast Satellite (proposed)*
Peak-to-peak deviation	25 MHz	13 MHz
RF bandwidth	38 MHz	27 MHz
Sound transmission	digital sound-in-syncs	6 MHz fm sub-carrier

It should be appreciated that, to enable satisfactory reception on relatively simple receivers and with domestic aerials, a satellite to the above broadcast specification would require transmitter power much higher than those commonly used for telecommunications satellites. OTS however, will enable evaluation of the proposed direct broadcasting system by using a low-noise receiver to compensate for the reduced satellite power. It will be noted that, for Eurovision and for satellite broadcasting, the prime modulation system will be frequency modulation, the main difference being in the occupied spectrum and the means of transmitting the accompanying sound channel(s).

OTS transmissions via the 'spotbeam' facility provide an equivalent isotropically radiated power (eirp) approximately 8·2 dB greater than that of the transmissions via the 'Eurobeam A' satellite aerial. Similarly the continuous beacon B1 has an eirp 11·4 dB, greater than that of the telemetry beacon TM.

The OTS is a geostationary, three-axis stabilised satellite with an anticipated positional stability of $\pm 0{\cdot}1°$ in both north-south and east-west directions. The polarisation discrimination of an aerial decreases rapidly as the distance from its centre boresight increases, (Fig. 2); and for the type of propagation experiments envisaged, an aerial of more than about 3 m diameter would require tracking to maintain adequate xpd. Since the satellite movements are both cyclic and diurnal, the xpd resolution can be improved during propagation measurements by applying correction after recording.

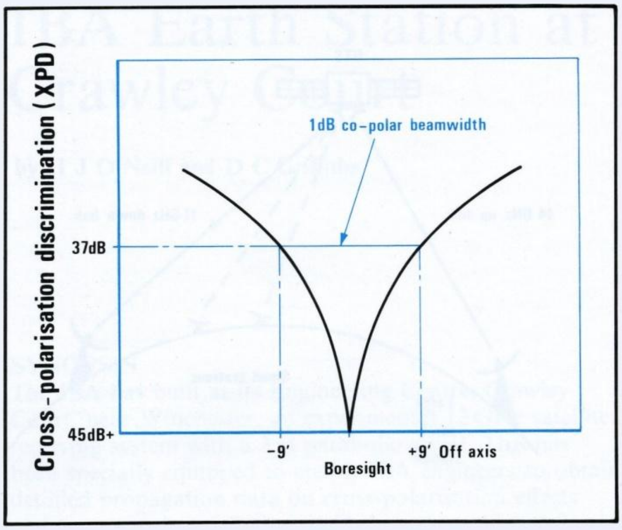


Fig. 2. The polarisation discrimination of a satellite receiving aerial decreases rapidly away from its centre bore-sight direction. A 12 GHz aerial of more than about 3 m diameter would require tracking of the cyclic and diurnal movements of a geostationary satellite of realisable performance. However, the cross-polarisation can be improved during propagation measurements by applying correction after recording.

The telemetry beacon, TM, provides linearly polarised signals, whereas the continuous beacon B1 uses circular polarisation and, as previously mentioned, has an eirp 11·4 dB higher. Therefore, the IBA intends to use the B1 beacon for the propagation measurements; and a carrier power of −129·6 dBw from a 3 m parabolic aerial is expected. Since detection of cross-polarised signals to at least 30 dB below that level is desirable, it is necessary to restrict receiver noise bandwidth to less than 10 Hz. The use of such narrow noise bandwidths (necessitating a very high order of frequency stabilisation) means that the necessary snr can be achieved without signal frequency amplification by means of a low-noise amplifier (lna).

Two transponder chains in the OTS are capable of being used for wideband television signals: the 40 MHz channels are fed to the 'Eurobeam A' aerial; the 120 MHz channels to the 'spot-beam' aerial which has an eirp 8·2 dB higher than that of 'Eurobeam A'.

Whereas satellite distribution experiments will be conducted with the 40 MHz and 120 MHz systems, the satellite broadcasting tests will use the 120 MHz channel with a deviation of 13 MHz and a corresponding receiver bandwidth of approximately 27 MHz: see Fig. 3.

Theoretically, transmission of television signals from the 'spotbeam' satellite aerial should produce a

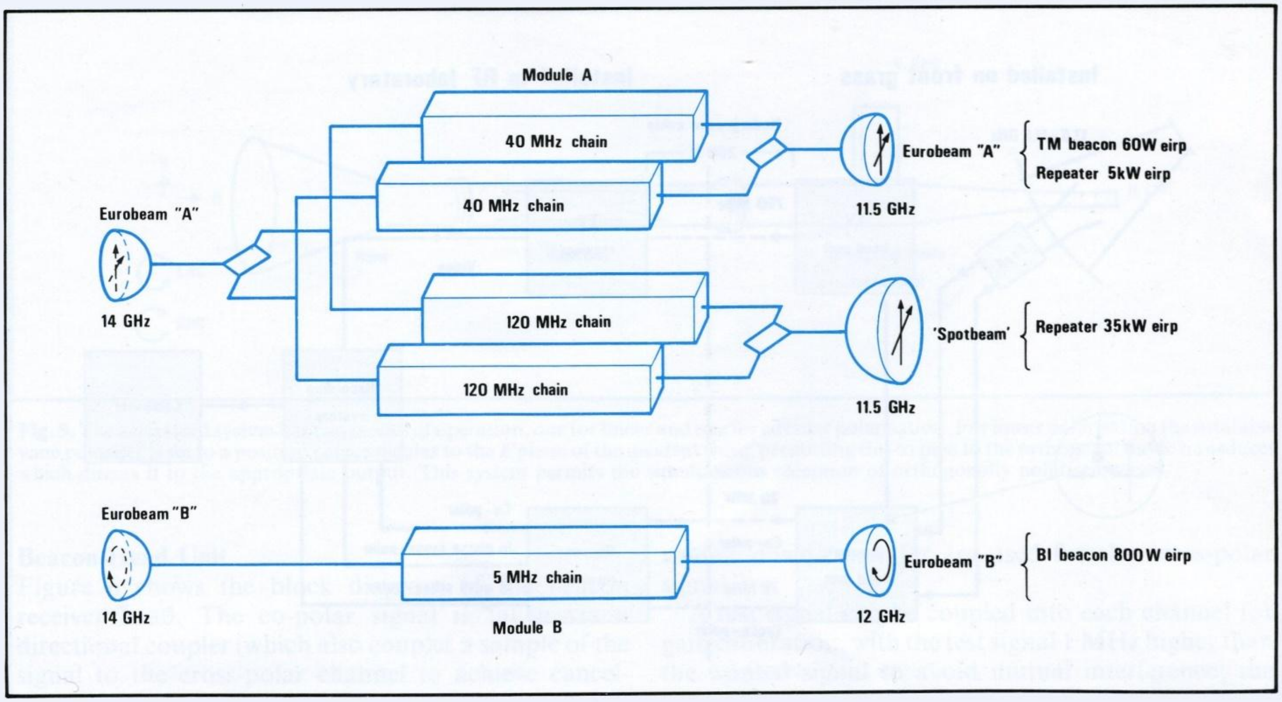


Fig. 3. The communications payload of the European OTS together with the eirp of the signals of particular interest. Reception of television signals should be possible by quite compact earth stations provided that the 'spotbeam' aerial is being used.

carrier power, available at the output of a 3 m earth station aerial, of −111·6 dBw. This compares to a typical input level of a terrestrial microwave programme link of the order of −60 to 70 dBw. With a receiver noise temperature of 200°K a luminance weighted snr of 47 dB should be obtained. Use of higher deviation of the fm signal would give improved video snr, but would result in a reduced margin above the demodulator threshold.

Crawley Court Earth Station

A block diagram of the basic arrangement of the IBA earth station is shown in Fig. 4. Three outputs are taken from the aerial: an output corresponding to the co-polar component of the satellite beacon; an output corresponding to the cross-polar component of the beacon; and an output corresponding to the television signal. The first two outputs are circularly polarised; the third is linearly polarised. To minimise feed-loss it is necessary to share one feed output between the beacon and the television signal.

The three head units are each housed in a weatherproof box mounted directly behind the aerial. The aerial is installed in front of Crawley Court and the signals are routed via underground coaxial pair cable to the IBA RF Laboratory where they are amplified, demodulated and recorded.

Aerial and Feed System

The 3 m aerial is a paraboloid consisting of glass-reinforced plastics with a fine wire-mesh reflecting surface, providing a 3 dB beam-width, at the operating frequency, of approximately 0·5°. A Cassegrain feed has a specially shaped sub-reflector designed to give high-efficiency and low cross-polarisation performance. The latter characteristic is of special importance for the proposed experiments, one object of which is to determine the cross-polarisation induced by the propagation path, rather than that due to fluctuations in the position of the satellite and forming part of the so-called 'equipment' cross-polar components. These also include those due to imperfections of the waveguide circuitry in both the satellite and earth station, which form 'fixed' components, and those which vary randomly, for instance due to pointing angle variations of the receiving aerial arising from wind gusts.

Fixed components of the cross-polar signal can be reduced by a cancellation circuit wherein a small fraction of the co-polar signal serves to cancel the

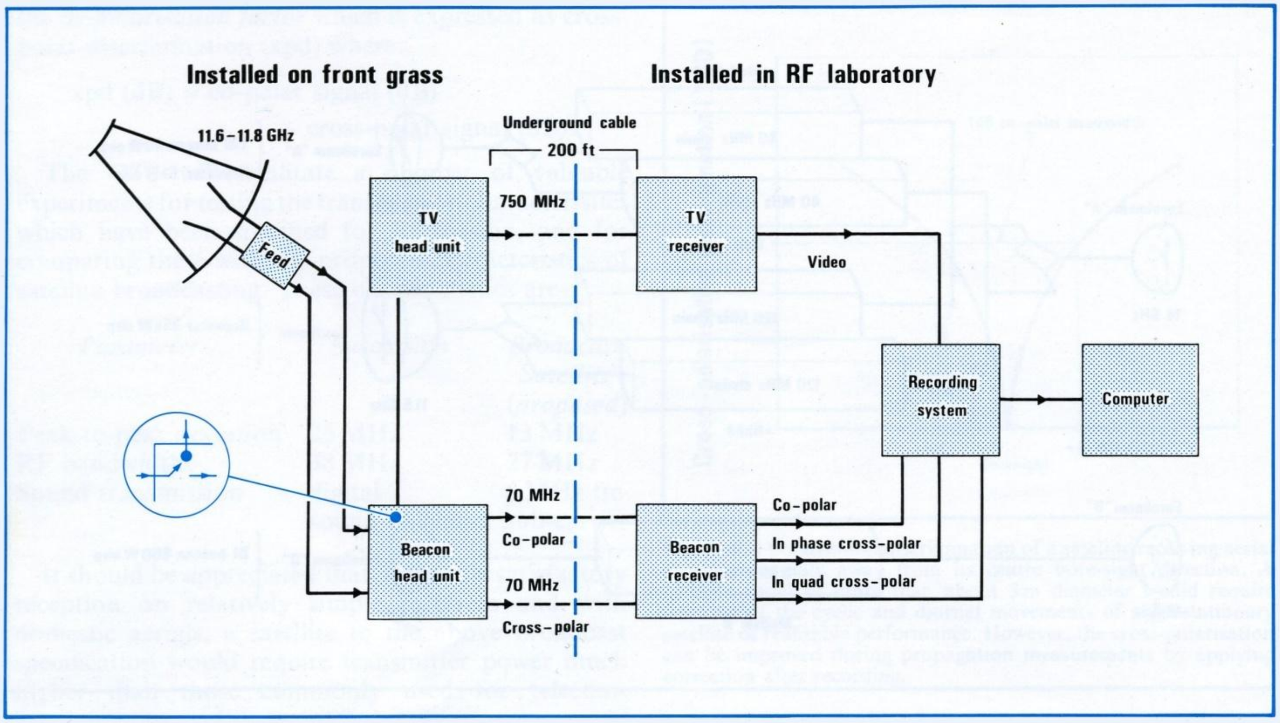


Fig. 4. The general arrangement of the Crawley Court earth station. Two beacon head units are used for receiving the co-polar and the cross-polar components of the B1 continuous beacon transmissions, with a separate television head unit for the reception and monitoring of television performance. The three head units are each housed in a waterproof box directly behind the 3 m parabolic aerial on the lawn in front of Crawley Court, and the signals are routed via underground co-axial cable to the RF laboratory of the IBA Experimental and Development Department where the main receiver and recording units are located.

unwanted cross-polar component. Periodic components could be reduced by a tracking system. Random components due to wind gusts can be minimised only by good mechanical engineering of the aerial and its associated mounting. For the aerial at Crawley Court, cross-polarisation due to wind deflections are expected to prove less than 45 dB below the co-polar level for wind gusts up to 70 mph.

The feed system (Fig. 5) has two modes of operation; for linear or circular polarisation. For linear polarisation the polariser (a rotatable vane in circular waveguide giving a 90° phase shift) is set to a position perpendicular to the *E* plane of the incident wave, permitting the incident wave to pass to the orthomode transducer. This directs the signal to one of two outputs, depending upon its polarisation. This permits simultaneous reception of orthogonally polarised waves, although one will have a 90° phase shift which can be neglected.

For circularly polarised signals, the polariser is rotated to a position of 45° to the plane of the orthomode transducer outputs. The incoming wave is then converted by the polariser into a linearly polarised wave which is then directed by the orthomode transducer to the appropriate output. If both right-hand and left-hand circularly polarised waves are being received simultaneously, the signals will appear at both output ports.

The complete feed system is arranged so that it can be rotated through 90°. Since the polariser can be rotated independently, right-hand or left-hand circularly polarised signals can be paired with either vertically or horizontally linearly polarised signals by appropriate orientation of the feed and the polariser. Hence, the combined television signal and cross-polar beacon signal is available at one output of the orthomode transducer. This output is taken to a waveguide switch which routes the cross-polar beacon signal to the beacon head unit, and the television signal into the television head unit, providing a simple, low-loss feed system for the shared feed. The other output from the orthomode transducer, containing the co-polar beacon signal, is taken to the beacon head unit.

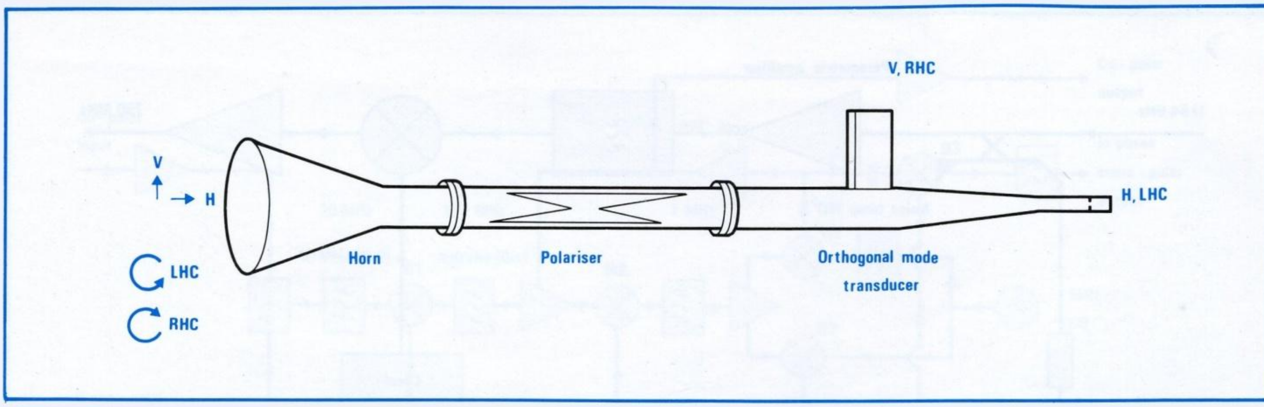


Fig. 5. The aerial feed system has two modes of operation, one for linear and one for circular polarisation. For linear polarisation the rotatable vane polariser is set to a position perpendicular to the *E* plane of the incident wave, permitting this to pass to the orthogonal mode transducer which directs it to the appropriate output. This system permits the simultaneous reception of orthogonally polarised waves.

Beacon Head Unit

Figure 6 shows the block diagram of the beacon receiver head. The co-polar signal is taken via a directional coupler (which also couples a sample of the signal to the cross-polar channel to achieve cancellation) to a narrow-band filter and is then down-converted to 70 MHz. A similar narrow-band filter and similar down-converter are used for the cross-polar signal.

A test signal can be coupled into each channel for gain calibration, with the test signal 1 MHz higher than the wanted signal to avoid mutual interference; the main local oscillator frequency is likewise shifted by 1 MHz to maintain the i.f. at 70 MHz.

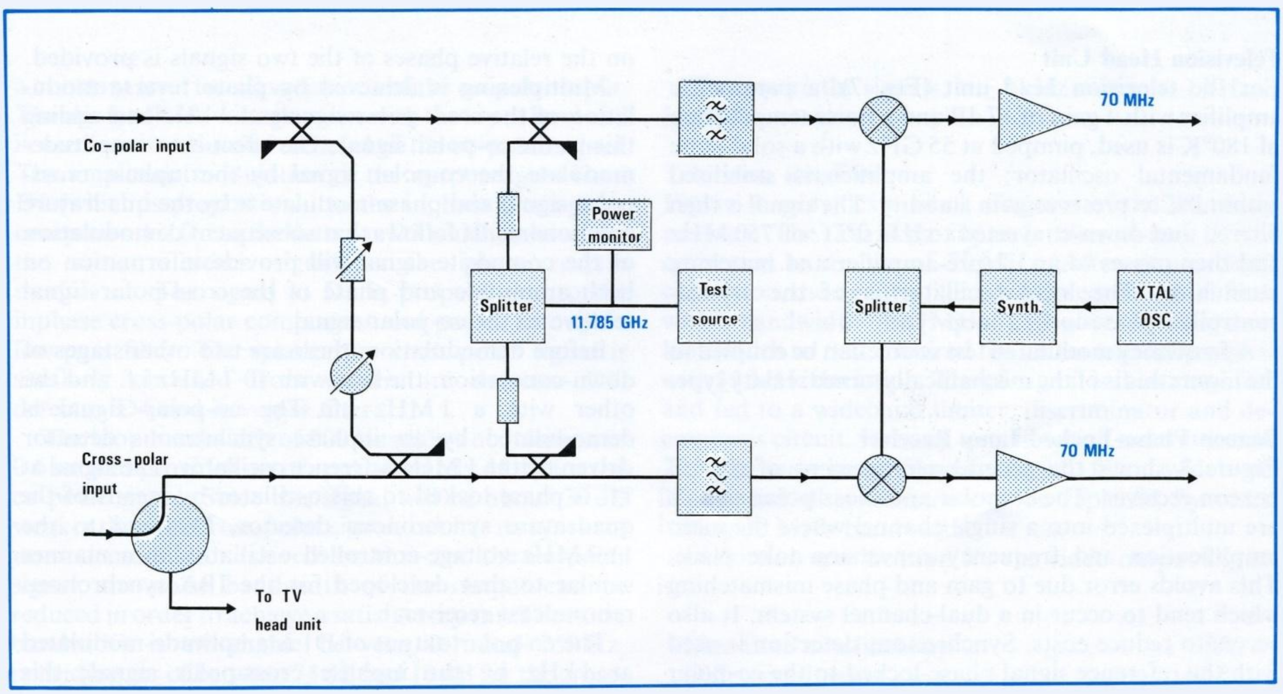


Fig. 6. Block diagram of the dual beacon receiver head unit (mounted directly behind the aerial) which down-converts the co-polar and cross-polar signals into each channel for gain calibration, off-set by 1 MHz to avoid mutual interference.

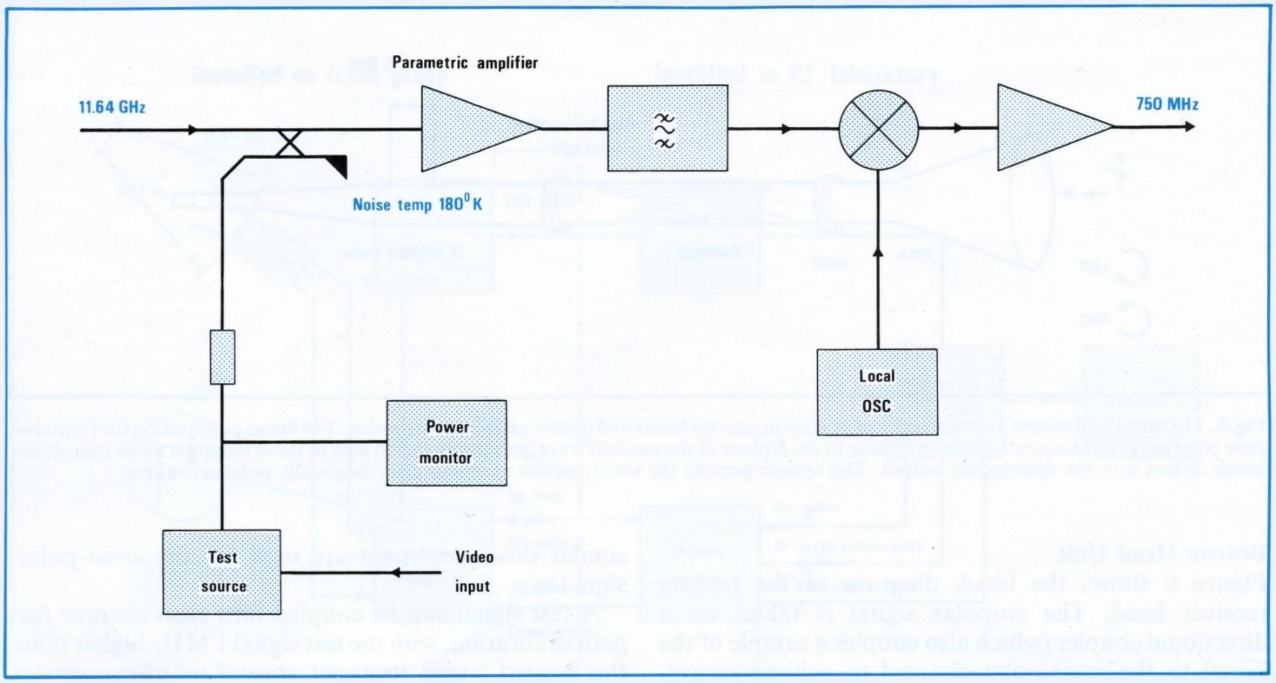


Fig. 7. The low-noise television receiver head unit has a temperature-stabilised parametric amplifier, pumped at 55 GHz by a solid-state fundamental oscillator to provide a gain of 17 dB and an equivalent noise temperature of 180°K. The signal is then filtered and down-converted to an i.f. of 750 MHz. The local oscillator is of the crystal-controlled, phase-locked-loop type. A frequency-modulated test source can be coupled to the input.

Television Head Unit

For the television head unit (Fig. 7), a parametric amplifier with a gain of 17 dB and a noise temperature of 180°K is used, pumped at 55 GHz with a solid-state fundamental oscillator; the amplifier is stabilised within 1°C to preserve gain stability. The signal is then filtered and down-converted to a first i.f. of 750 MHz and then passes to an i.f. pre-amplifier and matching attenuator. The local oscillator is of the crystal-controlled phase-locked-loop type.

A frequency modulated test source can be coupled to the input; this is of the mechanically-tuned, cavity type.

Beacon Phase-Locked-Loop Receiver

Figure 8 shows the general arrangement of the pll beacon receiver. The co-polar and cross-polar signals are multiplexed into a single channel where the main amplification and frequency conversion take place. This avoids error due to gain and phase mismatching which tend to occur in a dual-channel system. It also serves to reduce costs. Synchronous detection is used with the reference signal phase-locked to the co-polar signal, detecting the much weaker cross-polar signal with a clean reference signal; in addition, information on the relative phases of the two signals is provided.

Multiplexing is achieved by phase reverse modulation of the cross-polar signals at 1 kHz and adding this to the co-polar signal. The effect is to amplitude-modulate the co-polar signal by the inphase cross-polar signal and phase-modulate it by the quadrature components. It follows that subsequent demodulation of the composite signal will provide information on both amplitude and phase of the cross-polar signal relative to the co-polar signal.

Before demodulation, there are two other stages of down-conversion, the first with 10·7 MHz i.f. and the other with a 1 MHz i.f. The co-polar signal is demodulated by an inphase synchronous detector driven by the 1 MHz reference oscillator. The signal at i.f. is phase-locked to this oscillator by means of the quadrature synchronous detector, D2, and to the 11·7 MHz voltage-controlled oscillator, in a manner similar to that developed for the IBA synchronous rebroadcast receiver.

The co-polar output of D1 is amplitude-modulated at 1 kHz by the inphase cross-polar signal; this modulation is removed by filtering, and the output used for an agc system which holds the output of D1 to

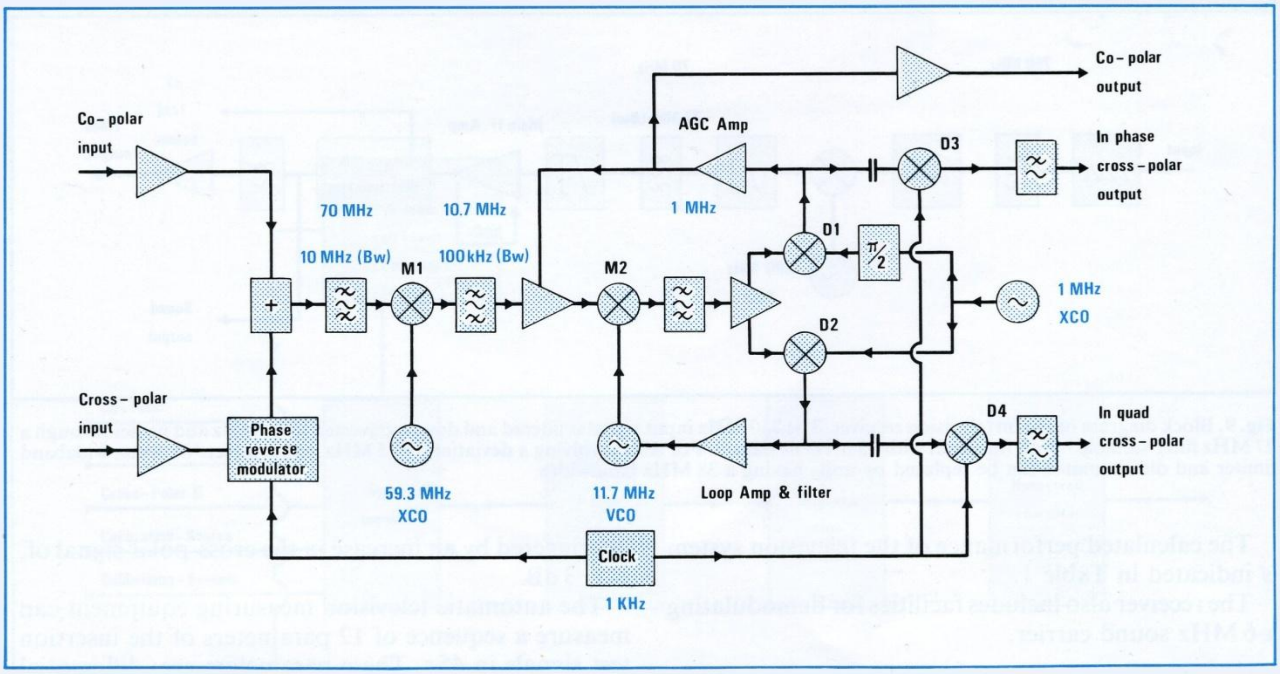


Fig. 8. General arrangement of the beacon receiver which uses a phase-locked-loop system. The 70 MHz co-polar and cross-polar signals from the head unit are multiplexed into a single channel with intermediate frequencies of 10 MHz and 1 MHz to avoid errors due to the differences in gain and phase characteristics of two-channel systems. Synchronous demodulation is used, and the loop bandwidth is 200 Hz. Noise bandwidth is switchable between 0·1 and 250 Hz.

a constant level for all variations of the co-polar input. The agc feedback voltage varies with the input level and is used as a measure of the level of the co-polar signal. The amplitude modulation of the output signal from D1 (which is proportional to the inphase cross-polar component) is fed to the detector D3 which is driven by the same reference signal as the phase reverse modulator. The signal at D3 is proportional to the inphase cross-polar component and passes through a low-pass filter. The quadrature cross-polar signal is similarly obtained from quadrature detector D2, detector D4 and low-pass filter.

The loop bandwidth of 200 Hz allows acquisition in 0·6 sec and provides snr of approximately 41 dB for the co-polar signal. Since this signal will be about 30 dB weaker than the cross-polar signal, but has its synchronous demodulator 'slaved' to that for the co-polar signal, the noise bandwidth of the output can be reduced in order to achieve a satisfactory snr. The noise bandwidth is switchable between 0·1 and 250 Hz, providing snr of between 74 dB and 10 dB for the cross-polar signal, in comparison to the 41 dB of the co-polar signal.

To acquire the signals, a ±3 kHz sweep, at 1 kHz/s, is used.

Television Receiver

Figure 9, provides a block diagram of the television receiver. The 750 MHz input is filtered and down-converted to an i.f. of 70 MHz. After group delay correction, the signal is filtered in the equalised i.f. filter with a bandwidth of 27 MHz. This governs the system bandwidth to that required for an fm television signal with 13 MHz deviation. The i.f. signal is then amplified and fed to a wideband limiter, discriminator and de-emphasis circuit. For any tests in which a deviation of 25 MHz may be employed, the i.f. filter, wideband limiter and discriminator can be replaced by units having 38 MHz bandwidth.

Distortion specification for the video output signal is:

Line-time non-linearity	5%
Differential gain	±5%
Differential phase	±5°
Chrominance/gain luminance inequality	±5%

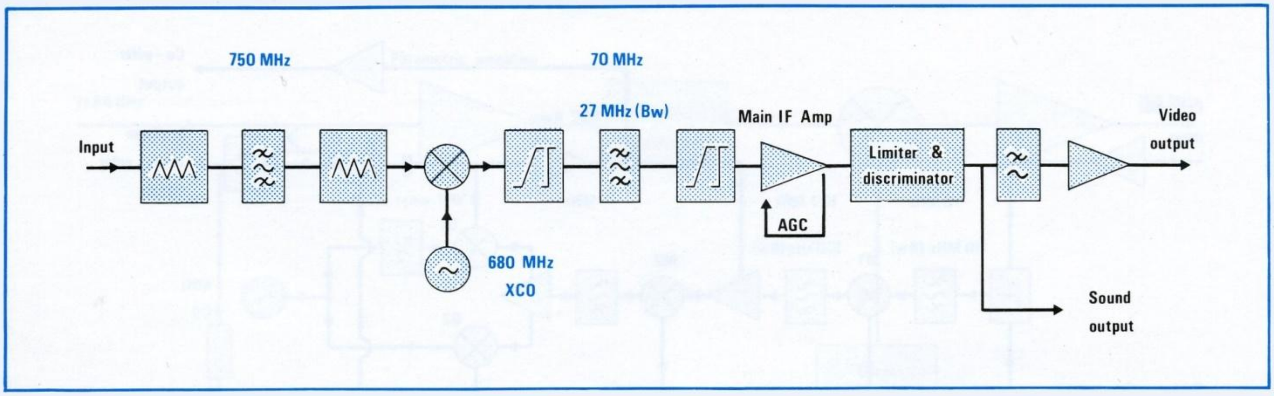


Fig. 9. Block diagram of the fm television receiver. The 750 MHz input signal is filtered and down-converted to 70 MHz and passes through a 27 MHz filter suitable for an fm signal with 13 MHz deviation. For tests involving a deviation of 25 MHz, the complete i.f. filter, wideband limiter and discriminator can be replaced by units having a 38 MHz bandwidth.

The calculated performance of the television system is indicated in Table 1.

The receiver also includes facilities for demodulating a 6 MHz sound carrier.

Measurement and Recording System

The general arrangement of the measuring and recording system is shown in Fig. 10. Basically, a conventional data logger is used for propagation measurements, but the system used for television measurement is believed to be unique, since it is based on automatic measuring equipment. Outputs from these units are taken to a tape punch machine and/or teleprinter and thence to a Honeywell computer for analysis.

The logic and timing unit has a variable limit detector for controlling the sampling speed of the data logger. For example, if the co-polar signal fades by more than a predetermined limit (say 2 dB), the sampling interval automatically decreases from 1 min to 10 s. A similar decrease in sampling interval would be triggered by an increase in the cross-polar signal of, say, 3 dB.

The automatic television measuring equipment can measure a sequence of 12 parameters of the insertion test signals in 45 s. These parameters are: differential gain; differential phase; line-time non-linearity; video snr; chrominance/luminance gain and delay inequalities; chrominance/luminance crosstalk; 2T *K* rating; pulse and bar ratio; bar tilt; bar height; and sync pulse height. It is proposed to repeat the sequence at 1 min intervals.

Measurements

The signals of the continuous beacon B1 will be transmitted continuously throughout the life of the satellite, allowing the Crawley Court earth station to record continuously the co-polar signal level, and the cross-polar signal level and phase, relative to the co-polar signal. While a sampling interval of about one minute can provide statistical distributions of the

TABLE I. CALCULATED PERFORMANCE OF THE CRAWLEY COURT EARTH STATION TELEVISION RECEIVER

TYPE OF SIGNAL	DEVIATION OR BIT-RATE	I.F. BANDWIDTH	99 % THRESHOLD MARGIN*	VIDEO SNR (UNWEIGHTED)	APPROX. PICTURE GRADE
Eurovision fm-tv	25 MHz	38 MHz	2·6 dB	40 dB	1·0–1·5
Direct-broadcast fm-tv	15 MHz	27 MHz	4·0 dB	36 dB	1·5–2·0
Digital	60 Mb/s	38 MHz	—	—	Bit error rate 1 in 10^6

* 1·6 dB fade, 1·1 dB up-path noise. 99 % represents percentage of time when these figures are unlikely to be exceeded.

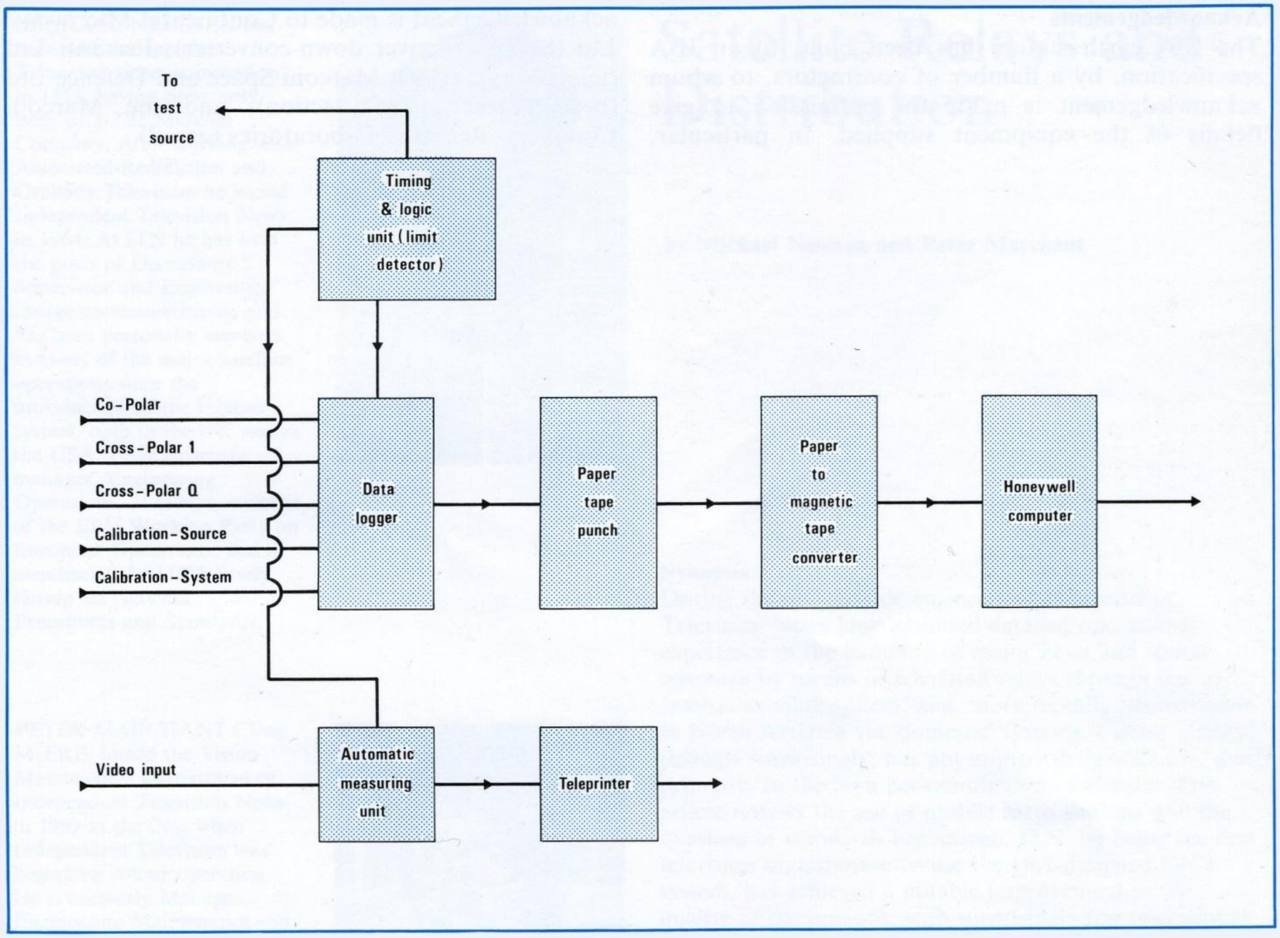


Fig. 10. The general arrangement of the measuring and recording system using a data logger for shf propagation measurements and automatic measuring equipment operating on interval test signals. The logic and timing unit has a variable limit detector to control the sampling speed of the data logger, in order to increase the sampling rate either during fades of the co-polar signal or on increase of the cross-polar signal.

propagation path at 12 GHz, the variable sampling rate is felt to be of special value for investigating the precise nature of individual events. For example, previous observers have reported that abrupt changes in cross-polar discrimination coincided with lightning strikes when monitoring the ATS-6 satellite beacons at 20 and 30 GHz.

The long-term objects of much of the work to be carried out by the IBA are those of analysing shf propagation effects and of determining how these might influence future satellite broadcasting at 12 GHz. The measurements should confirm (or reject) attenuation data previously obtained from radiometer recordings, currently used in the planning of broadcast systems.

The range of television tests which the European broadcast organisation are anxious to carry out via the OTS is considerable, and participants are clearly anxious to make full use of the test signals originating in the earth stations of their individual countries; however agreement on the inclusion of the test line signal has been reached.

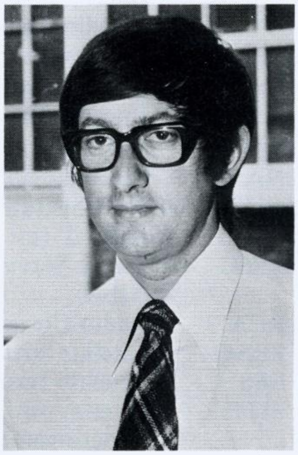
At a later stage a digital television demodulator may be used for experiments in the transmission of 60 Mb/s digital television. It would then be useful to compile (in addition to subjective assessments) error statistics, jitter performance and evaluation of bit reduction, error concealment and coding techniques.

Acknowledgements
The IBA earth station has been built, to an IBA specification, by a number of contractors, to whom acknowledgement is made for permission to give details of the equipment supplied. In particular, acknowledgement is made to Continental Microwave Ltd (beacon receiver down-converter); Ferranti Ltd (television receiver); Marconi Space and Defence Ltd (beacon receiver i.f. section); and the Marconi Company, Research Laboratories (aerial).

Satellite Relays and Distribution

by Michael Neusten and Peter Marchant

MICHAEL NEUSTEN has been with Independent Television since its inception in 1955, having previously been with The Marconi Company. After working with Associated-Rediffusion and Granada Television he joined Independent Television News in 1964. At ITN he has held the posts of Operations Supervisor and Engineer-in-charge communications, and has been personally involved in many of the major satellite operations since the introduction of the Intelsat system, both in the UK and in the USA. He is currently manager, Engineering Operations, at ITN, a member of the EBU Working Party on European Operations, and a member of the ITCA Study Group on Network Procedures and Standards.



PETER MARCHANT CEng, MIERE, joined the Vision Maintenance Department of Independent Television News in 1969 at the time when Independent Television was beginning colour operation. He is currently Manager, Engineering Maintenance and Projects, leading the development and maintenance teams which have helped pioneer the use of digital techniques in television with the operational use of DICE, Teletext and complex digital character and graphics generation equipment. He is a member of the IBA Working Party for the 'Code of Practice for Television Studio Centre Performance' and a member of the ITCA Study Group concerned with 'fundamentals'—i.e., dealing with current topics such as fibre optics, new cameras, and special techniques of testing.

Synopsis

During the past decade engineers of Independent Television News have acquired detailed operational experience in the handling of major news and sports coverage by means of television relays through the Intelsat satellite system; and, more recently, its extension in North America via 'domestic' systems. Circuit quality, perhaps surprisingly, has not improved significantly, due primarily to the high per-minute cost of circuits. This article reviews the use of mobile earth stations and the question of standards conversion. ITN, by being the first television organisation to use the IBA-designed DICE system, has achieved a notable improvement in the quality of conversions; with surprisingly few operational problems in the first major introduction of digital-video into television broadcasting. This has been helped by use of specially designed test equipment. Some account is also given of bandwidth compression and the prospects for digital transmission systems.

Although in Europe operational use of direct broadcasting from satellites may still be several years distant, Independent Television News has already considerable experience in the practical use of satellites. This is the experience gained in using the Intelsat communications satellites as a contribution input system. In such applications engineers are concerned not only with the technical parameters but also with the important question of tariffs and operational structures. We need to know what can be done, how well and how quickly it can be effected, and whether satellites can be used economically for regular routine exchanges as well as for the occasional one-off event.

It is easy to become rather neurotic about intercontinental relays and broadcasting: one minute elated—since satellites make possible things which might not be achieved in any other way; and the next minute despondent at the way the system, certainly no longer 'state of the art', is working out in practice. Those concerned directly with the day-to-day exchanges of news and sports coverage have little time to consider the engineering problems, still less to spare on the inter-governmental politics of the communications satellites: the interest ultimately reduces to two holes in a jack field and the cost and operational convenience of activating them. The maze of multi-initialled organisations (see Table I) is perhaps a reflection of the labyrinth of international telecommunications. It is also interesting, if unrewarding, to note that wideband communications satellites were developed only a shade ahead of wideband ocean cables. Today, it would be technically feasible to carry live colour television pictures across the Atlantic by cable;

TABLE I
SPACE ORGANISATIONS, ETC.

ATS	Application Technology Satellites, a NASA programme of experimental communications, meteorological and navigational satellites.
BSDC	British Space Development Company—a consortium formed in 1961.
CCST	Consultative Committee on Satellite Telecommunications (UK).
CETS	European Conference on Satellite Telecommunications.
CNES	French National Centre for Space Studies.
Comsat	Communications Satellite Corporation (US corporation that acts as manager for Intelsat).
Cospar	Committee on Space Research of the International Council of Scientific Unions (headquarters, Paris).
ECS	European Communications Satellite project.
ELDO	European Launcher Development Organisation (now forms part of ESA).
ESA	European Space Agency (formed from ELDO and ESRO).
ESRO	European Space Research Organisation (now forms part of ESA).
Eutelsat	European Telecommunications Satellite Organisation (part of ESA).
GSFC	Goddard Space Flight Centre, Maryland, USA.
GTS	Global Telecommunications System.
HET	Health, Education, Telecommunications (experiments on ATS6, etc.).
Intelsat	International Telecommunications Satellite Consortium.
Inter-sputnik	International Satellite Communications System headed by USSR.
IUCAF	Inter-Union Commission on Allocation of Frequencies.
NASA	National Aeronautics and Space Administration (USA).
OTS	Orbital Test Satellite project of ESA.
PSSC	Public Service Satellite Consortium (USA).
RCA	Radio Corporation of America.
SBAG	Satellite Broadcasting Advisory Group.
SBS	Satellite Business Systems.
SITE	Satellite Instructional Television Experiment (India 1975–76 with ATS6).
STOC	Satellite Technical Operational Committee.
Telesat	Telesat Canada—Canadian corporation for satellite communications (Anik satellites, etc.). Also Teleglobe Canada.
UNSC	United Nations Space Committee.
UPITN	International Television News Agency (United Press and Independent Television News).
WARC-ST	World Administrative Radio Conference for Space Telecommunications (Geneva, 1971).

although, because cables can deal only with point-to-point routes, administrations would find it uneconomical to provide cables for omnidirectional traffic between the 20–30 countries within the Atlantic basin and capable of access to satellite systems.

Intelsat

Available to all users are the expanding networks of the Intelsat system. There are currently in operational use two Intelsat IVA satellites stationed for the Atlantic services, one Intelsat IV in the Indian Ocean, and one Intelsat IVA in the Pacific. There are also three 'spares' in orbit. Earlier Intelsat satellites have been abandoned in space, on account of their limited capabilities rather than for technical reasons: Table II. Basic reliability has been extremely good, design lifetimes often exceeded.

There are now no less than 63 earth stations within the Intelsat system able to transmit television signals to the satellites and several more equipped only to receive such signals. To be accepted within this worldwide system, all stations and operating authorities have to undertake to comply with the official 'Operating Instructions for Intercontinental Television Transmissions'—generally referred to as the 'Golden Book' of the business. Yet, the question arises: in practice do they, can they, comply with those recommendations?

It would be interesting to learn which PTTs have good short-notice booking office procedures with out-of-hours arrangements, or which earth stations have

TABLE II
INTELSAT SATELLITES

	INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV	INTELSAT IVA	INTELSAT V
First launching	1965	1967	1968	1971	1975	1979 (Estd)
DC power (watts)	33	75	125	450	600	1200
Total rf power (watts)	10	18	20	72	104	198·5
Transponders	2	1	2	12	20	27
Total usable bandwidth (MHz)	50	130	450	432	720	2241
Total two-way telephone channels (approx.)*	240	240	1200	4000	6000	12 000
Alternative TV facility (channels)*	1	1	4	12	20	40–50
Antenna beam(s)	11° × 360° centred + 7°	12° × 360° centred equator	1 Global beam 20° × 20°	1 Global beam 17° × 17° 2 spot beams 4·5° × 4·5°	1 Global beam 18° × 18° 2 hemi-beams 12° × 4°	1 Global beam 18° × 18° 2 hemi-beams 14° × 5° 2 zonal beams 9° × 3° 2 steerable spot beams for 11/14 GHz East spot 3·2° × 1·8° West spot 1·6° × 1·6°

* Note that the capacity of a satellite varies according to the way it is used. Significant factors are the number and strength of the carriers; the type of modulation; the method of access; and the distribution of traffic on the various antenna beams, and the characteristics and requirements of the earth stations.

In mid-1977 the number of countries participating in INTELSAT was 95.

(This table has been compiled with the assistance of the Post Office Space Systems Development Division)

permanent two-way video circuits available for connection to local broadcasters.

Again, how many PTTs handle sound, vision, and co-ordination circuits through only one control room? Much benefit would accrue if all did so.

Such matters are clearly vital to the broadcasters but would appear to be regarded as matters of only local concern to the PTTs—i.e., something to be implemented only when finance is readily available.

When intercontinental relays still had novelty value (and publicity value for telecommunications administrations) it was not unusual for broadcasters to be provided with an inaugural transmission period during which satellite television circuits were available free of charge. Probably, few broadcasters appreciate how lucky they were. Today, effectively, the cost of setting-up a 10-minute news transmission (charged from international 'Gateway' to 'Gateway') is about £1100. This gives the broadcaster immediacy and the viewer 'live' news but, at that price, it can be justified for only news or the most important sportscasts. The high cost of international satellite circuits—once hailed as opening the way to 'sixpenny' ($2\frac{1}{2}$ p) telephone circuits to Chicago—limits the rate of growth of television traffic and seems to bear little relationship to the cost of distribution circuits on the new generation of 'domestic' satellites.

Satellite Circuit Quality

The nature of the traffic (primarily major news) has also had an effect on the quality of the pictures received during intercontinental relays. The broadcaster has usually only a minute in which to phase-up colour bars, and the circuits have to be accepted virtually on 'go/no-go' terms. Since most television traffic is still with North America, where there are usually a number of 'carriers' in a long chain, there is no individual body in a position to accept responsibility for the entire route. It is not always appreciated that terrestrial television 'land-lines' within the USA are the responsibility of three separate 'carrier' organisations working on a rota basis: RCA, Western Union and AT&T, each taking turn as 'carrier of the month'. Intelsat's satellite management organisation—the American Comsat Corporation—regards each of these three USA 'carriers' as its customer. At the start of the 'booked time', Comsat simply switches the satellite circuit to the carrier of the month, giving the broadcasters at both ends little time for line-up of standards converters and overall circuit 'mop-up' equalisation.

Where signals arrive from NTSC-originated sources, it is still a regular experience to find phase errors of up to 60° when switching from master control rooms in New York to video tape machines in other parts of the country. European broadcasters, through EBU, have exerted much effort towards persuading the Comsat Corporation to define the customer, as do CCITT and CEPT, and to give one or two minutes of line-up time before the official start of each booking. As a result of some 12 years of discussion this situation has been largely achieved in practice, although formally it is still regarded as only a concession.

The international tariffs have had a further unfortunate effect on the technical quality of the satellite pictures. Since there is little use of satellites except for major events, any dedicated television circuit remains idle for a large part of the day; and, despite the high tariffs for television, it is possible for administrations to earn very much more revenue from conventional telephone and telegraph usage. One result is that television channels are now confined to the two halves of a single transponder, instead of being able to use two transponders. This Intelsat arrangement, while understandable, has affected adversely the signal/noise ratio; the present 36 dB on Intelsat IV is, in fact, no better than that on the original Early Bird (Intelsat 1), circuits of 1965. Further, Intelsat have recently reduced the television capacity of the Indian Ocean satellite to one half-transponder circuit only.

Over the years it has been difficult to obtain meaningful measurements on operational satellite circuits because American broadcasters do not include interval test signals on their transmissions. Also the high going rate of $100 a minute is a strong disincentive to undertaking full-field test signal sequences. The first sustained operational measurements were those made under the aegis of the EBU during the 1976 Montreal Olympics when we took our own ITS generators to Canada.

Time and the Satellites

The first television programme transmission on the experimental Telstar satellite was made in the direction Europe to North America, and it is in this East-to-West direction that the bulk of the television traffic still flows. ITN acts as the originating end more often than do the American broadcasters. This is not only for financial reasons. The American network, ABC, for example, can take a news story from London at 22.30 GMT and still get it into their early evening newscast. A morning story from London on a noon satellite relay will be in time for the American breakfast shows. In the opposite direction, however, material prepared for a 1900 hrs transmission in North America does not reach

us until midnight, London time, when newscasts have ended for the day: it may just as effectively (and more economically) cross the Atlantic as air freight and still make ITN's *News at One* (1300 hrs).

Admittedly, apparently to increase circuit occupancy during low-traffic hours and to tempt broadcasters away from air freight, Comstat Corporation offers a night tariff (based on the North American 'night') at some 60 per cent of the peak tariff rate. This would be more tempting were it not that the saving on the satellite 'time' is liable to be absorbed by overtime charges incurred at the studio of origin in the running of vtr or telecine machines at night.

To the East and South these problems either do not exist or they operate in the reverse manner. ITN takes a lot of material from Australia, Israel, South Africa and so on. Even so, current 'unilateral' bookings on behalf of ITN are only about two per week. This figure is less than formerly; because, as other European countries become more satellite-minded, more of the satellite news inserts are booked jointly on behalf of Eurovision, and ITN benefits by participating in these multilateral transmissions.

Mobile Earth Stations

It is the 'down-link' from satellite-to-earth which imposes the greater requirement for very large parabolic aerials, due to the limited power flux permitted from the satellites; and it is possible to inject television transmissions into the Intelsat network from compact, transportable and mobile earth stations. The first ITN experiences of this type of operation were for the Pope's visit to Bogota in 1968, his visit to Uganda in 1969 and the Apollo 12 splashdown near the US aircraft carrier Hermes; the ship carried a 25 ft gyro-stabilised aerial and operated via the NASA ATS3 satellite. The Apollo pictures were sent via ATS3 to Houston, Texas, thence by land lines to the ETAM earth station and thence via Intelsat to Europe.

Since then, even smaller earth stations have been used. In 1972, a compact earth station was air-lifted to Peking Airport in two Boeing 727 aircraft and used to relay pictures of the first visit of President Nixon to China. These pictures reached the USA via the Intelsat Pacific satellite working via the Jamesburg earth station near San Francisco. The compact earth station remained in Peking and more recently served for transmitting pictures of other news events, including the lying-in-state of Mao Tse Tung. For the 1976 Olympic Games, Teleglobe Canada (the Canadian overseas telecommunications organisation) installed a temporary earth station on Mount Royal (Côte des Neiges), near Montreal, to augment their capability to distribute the coverage of these Games worldwide. Most of the pictures seen in the UK came via that station.

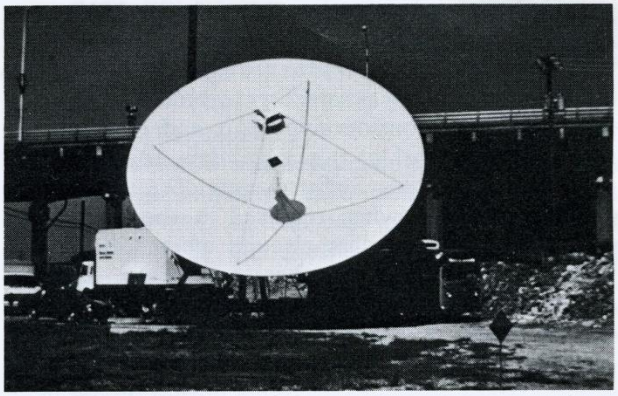


Fig. 1. A mobile earth station installed by Western Union on waste ground beside the Kemper Area in Kansas City during the 1976 Republican Convention. It is used with the 'Westar' domestic satellites.

There is a distinction between these 'demountable' stations and those which are more truly portable, just as there is a difference between the general requirements for handling small-module contribution facilities for news material and the current experiments aimed at either dedicated distribution circuits or direct broadcasting to small roof-top receiving terminals. These raise problems of control and administration which will need be resolved by Intelsat and future satellite and operating agencies.

Standards and Conversion

Independent Television News Ltd, besides producing the national and international news programmes for all the Independent Television Companies, is a part owner of UPITN (United Press and Independent Television News), a major international newsfilm and news video agency. ITN House, London, provides the UK facilities for this worldwide operation.

The availability of transatlantic satellite circuits via 'Early Bird' (Intelsat 1) in the mid-sixties and the increase in the air-freighting of video tapes, soon emphasised the problem of 50-field and 60-field television standards. From the early sixties onward ITN has owned a series of standards converters, some providing only line-rate conversion and others both line- and field-rate conversions. In 1969 Rank Precision Industries produced, to a BBC design, an analogue electronic field-store standards converter capable of NTSC–PAL conversion (and vice-versa). ITN purchased such equipment, and for four years it

provided conversion services not only for ITN's own bulletins but also for other broadcasters throughout the world. While such systems are capable of providing converted pictures of satisfactory technical quality, it is recognised that considerable effort and expertise are required in the work of aligning and maintaining these analogue converters. Such systems pose particularly difficult problems when required at short notice in connection with satellite circuits where, as already noted, line-up time is at a heavy premium. It would clearly be an advantage to have a converter that could confidently be expected to produce the highest grade pictures virtually at the touch of an 'on-off' switch.

The IBA started the development of a digital field-rate standards converter during the later part of 1971; and, by November 1972, a laboratory model was sufficiently ready to be used for the Eurovision satellite coverage of the American Presidential election. In March 1973 this one-way (525-line 60-field to 625-line 50-field) converter was transferred to ITN and installed at ITN House. Subsequently, the IBA design team developed a two-way model which incorporated also a number of other improvements. A two-way model built by the IBA, but similar to the design subsequently manufactured and marketed by Marconi Communication Systems Ltd, was installed at ITN House in May 1975. Since that date the ITN has provided an all-digital conversion service for its news programmes and for many customers worldwide.

It is interesting to note that the availability of DICE has not only vastly improved the quality of conversion but has greatly raised the expectations of engineers and viewers. There is a tendency for people to expect identical input and output pictures; while that ideal may be approached, it must be remembered that the luminance bandwidth of the 525-line system is inherently less than that of the 625-line system.

The accuracy with which colour hue and saturation are converted imposes stringent requirements on the decoders used for displaying input and output pictures, calling for a phase stability of the decoder of about 2° over the full range of mains-supply and environmental conditions. Experience indicates that most differences of hue, saturation, definition or ringing are caused by ancillary equipment rather than by DICE.

Since there are no operational controls to adjust, it might be thought unnecessary to have colour monitors permanently assigned to the input and output of the converter. In practice, these are needed, if primarily to convince customers that DICE really does do what it is claimed to do: i.e., convert pictures without introducing visible error.

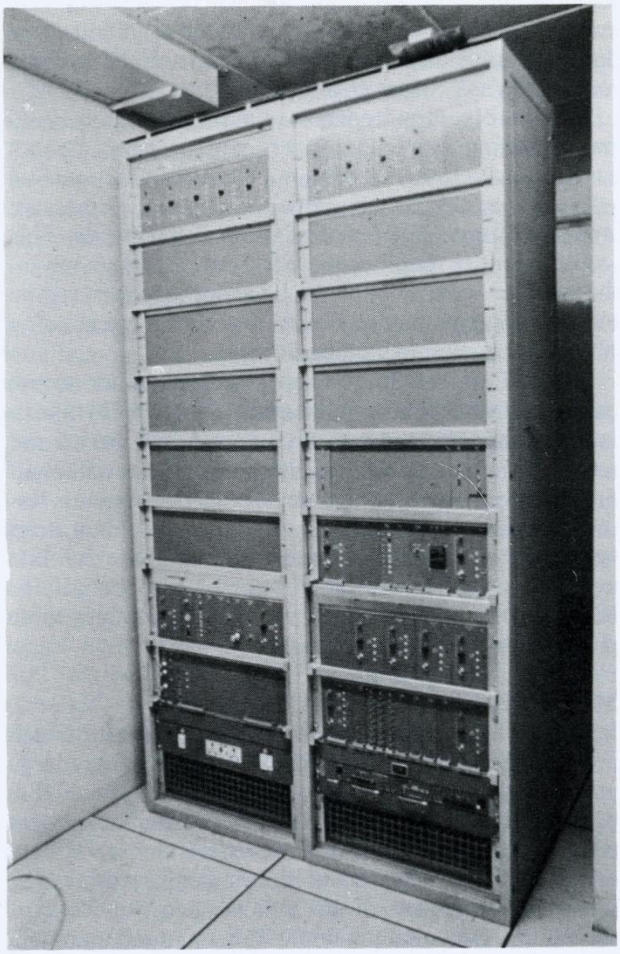


Fig. 2. The original DICE digital standards converter was installed at ITN House, London early in 1973, to be followed in 1975 with the two-way DICE II converter. Since 1975 all standards conversion at ITN between 525 and 625-line systems has been digital.

Occasional problems can arise due to non-standard material: for example, on one occasion certain 525-line material was found to have a line-blanking interval of 14 rather than 11 microseconds. The converter handled this material but treated the excess blanking if it were part of the active video signal. Thus, it produced a 625-line output with a 15 microsecond line-blanking interval.

When the first DICE arrived at ITN House in 1973 it was by far the most complex piece of digital video equipment ever to go into service, and represented a formidable challenge to maintenance engineers accustomed to analogue techniques. Yet, it was remarkable

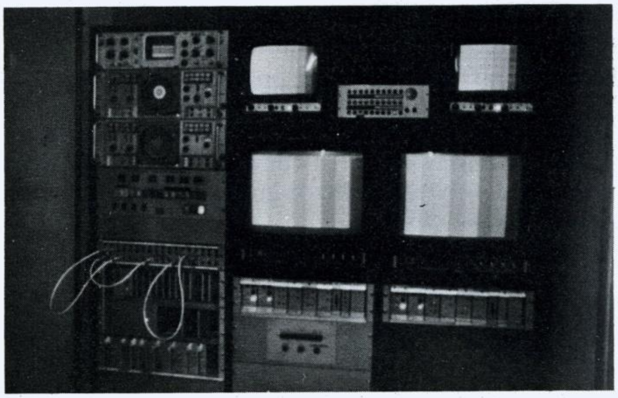


Fig. 3. Monitoring bay used for DICE II at ITN House. Since normally no correction is applied, it might be argued that there is no need of colour monitors permanently assigned to the input and output of DICE. This policy has not been adopted at ITN where it is felt that customers converting prestigious programmes need convincing, under good viewing conditions, that DICE really does produce excellent pictures. The monitors have, in fact, the negative role of showing no error.

how quickly engineers came to terms with the new equipment. Diagnoses, repairs and tests of many of the DICE boards are aided by special test jigs, including an 'arithmetic tester' and a 'store board tester'. These serve to eliminate many hours of manual testing which might otherwise be required. For example, printed-circuit boards are simply plugged into the store board tester and various automatic tests applied; light-emitting diode (led) indicators then show which shift register, if any, is functioning incorrectly.

Another useful aid is a 'roving dac'—a digital-to-analogue converter connected to a video monitor. By removing a circuit board, the 'roving dac' input lead can be plugged into the vacant edge-connector socket, and incoming data checked. When a fault has been traced to any particular board, a spare board can be substituted thus allowing the repair of the faulty board without pressure of time. In DICE, many boards are of common design, so that the number of spares is not unduly large. Indeed, the failure of certain boards would not result in complete loss of programme, but only in an often-acceptable reduction in picture quality.

The availability of DICE has paradoxically tended to make engineers less tolerant, rather than more so, of the shortcomings of the international television circuits supplied at short notice for news exchanges. There is also, now, a tendency for much more of the material, particularly that from North America, to be originated on $\frac{3}{4}$-in U-matic video cassettes rather than 16 mm newsfilm. An EBU Ad Hoc Committee, chaired by Dr Boris Townsend of the IBA, has been concerned with specifying suitable conditions for the international exchange of the material from electronic newsgathering (eng).

Bandwidth Compression

Most of the bandwidth compression systems proposed for analogue signals have achieved bandwidth compression only at the cost of greatly increased complexity both in equipment and operational handling. Currently, much attention is being devoted to bit-rate reduction for the transmission of digital video with particular reference to inter-city and international transmissions. While, theoretically, a high-quality pcm digital system for 625-line PAL colour requires a bit-rate exceeding 100 Mb/s, considerable progress is being made in reducing this rate; for example, early in 1977 IBA engineers demonstrated an experimental 34 Mb/s system which has a colour transmission performance more than adequate for the exchange of news and programmes.

Domestic Satellite Systems

Digital transmission via satellites has been authorised by the FCC (Federal Communication Commission—US) in their approval, given early in 1977, of a specialised domestic satellite communications service to be provided by Satellite Business Systems (SBS). The system envisaged for operational service would convey data, telephony and image transmission in the 12 and 14 GHz bands and would be the first such system to offer an all digital service.

It is not known when SBS will be operational, but there are already growing numbers of domestic satellite systems in North America, including the Canadian 'Aniks', the Western Union 'Westars' and RCA (Radio Corporation of America) 'American Satcoms'. (RCA currently lease a transponder on Intelsat as they formerly did on 'Anik').

The economics of these domestic systems are of particular interest. For example, the Western Union system, already connecting major towns within the USA, is bookable in 'quarter-hour' time slots thus tending to make the usage of it more economical than that of the equivalent terrestrial microwave network for which there is a minimum 'one-hour' charge.

Early in 1977, the FCC authorised the use of 'receive-only' earth stations with small-diameter (4·5 m or less) parabolic aerials.

Considerable use is already being made of audio-distribution via satellite, with 8 and 15 kHz channels, including audio pairs having a claimed performance of up to 65 dB signal/noise ratio. A prototype small aerial

system (10 ft diam.) developed for Western Union by Hughes Aircraft Company has the following minimum specifications: peak programme signal/noise ratio better than 54 dB; frequency response ± 1 dB, 50 Hz to 15 kHz, harmonic distortion nominally 1 per cent at peak programme level; stereo-pair gain differences less than 0·6 dB (50 Hz to 15 kHz), phase difference less than 15° (50 Hz to 15 kHz).

Numbers of cable-television stations are already making use of domestic satellites; and Rockwell-Collins have contracted to provide some 150 earth terminals for the Public Broadcasting System. These will use 10 m parabolic aerials. However at present many American networks continue to use terrestrial rather than satellite distribution circuits for their domestic operations.

G M DRURY, BEng, CEng, MIEE, was born in Wales and graduated in 1967 from Liverpool University. He then joined a telecommunications research department at GEC Hirst Research Centre working on high-speed digital transmission systems. In 1972 he joined the Post Office Space Systems Development Department to study applications of high-speed digital techniques to space satellite systems. In 1974 he joined the Video and Colour Section of IBA at Crawley Court

Digital Modulation for Satellite Systems

by Gordon Drury

SYNOPSIS

Although satellite technology has been developed primarily on the basis of wideband frequency modulation, the attractions of digital modulation have long been recognised. This article reviews the differences between frequency division multiple access (fdma) and time division multiple access (tdma). A discussion of the basic digital modulation systems leads to the conclusion that quadrature phase-shift keying (qpsk) would seem the most promising system, and the practical problems of qpsk modulation and demodulation are described.

Concurrently with the progression of communications satellites from science fiction to science fact another revolution, as significant if less dramatic, has been taking place throughout telecommunications: the growth in application of digital techniques. It is as though the wheel has turned full circle: for in the earliest days of electrical signalling, telegraphy (essentially a digital technique) was paramount.

A digital system is one in which the waveforms are selected from only a restricted number, as opposed to analogue systems in which the waveforms may have an infinite number of shapes and amplitudes. A binary digital waveform is one constrained to vary between only two voltage levels and which may therefore be processed by means of electronic switches whose two states ('on-off') may represent encoded digital information (mark-space or one-zero). For example, the Morse code is a binary digital code and requires only that a receiver can distinguish between the presence or absence of a signal. The Morse code can be used for sending messages at various speeds. Any effort to exploit basically similar techniques for the transmission of digital television in real time, however, inevitably involves the transmission of what is by comparison telegraphy at an extremely fast rate. Ideally, a digital television system would transmit at a rate of over one-hundred-million bits of information per second.

Early digital techniques did not remain dominant in communications and electronics primarily because the technology and knowledge of the theory of information coding were insufficiently developed. Early thermionic amplifiers were better able to cope with analogue techniques than with the high-speed switching needed for coding, into digital form, either audio or video images.

It was the semiconductor that provided a nearly ideal, high-speed electronic switch. This encouraged engineers to turn their attention to high-capacity digital systems which offered potentially the many advantages of robust signals which could be regenerated without cumulative degradations. Transistors and integrated circuits enabled engineers to exploit pulse code modulation which, though proposed by Alec Reeves in the 1930s, had remained virtually unused for more than two decades. The combination of high-speed electronic switching and greater awareness of the powerful tool of information coding has allowed engineers to return to the natural evolution of digital techniques for signal handling and transmission.

In 1972, the IBA developed and brought into operational use the first digital video system to make a

substantial contribution to television broadcasting: the DICE standards converter. This was soon followed by commercially manufactured digital time-base correctors for video tape recording which, in the USA, have brought about the rapid development of electronic news gathering (eng), followed in turn by frame and field synchronisers, digital noise reduction systems and other 'stand-alone' applications of digital video.

Early in 1977, the IBA demonstrated to other European broadcasters the major component parts of an all-digital television studio. At the same time the IBA also demonstrated an experimental digital encoding system in which 625-line composite PAL colour signals of good broadcast quality can be transmitted at bit-rates as low as 34 Mb/s, less than a third of the bit-rate normally required for pcm video.

These and other digital developments in the broadcasting field are progressing rapidly. Such developments must lead to the routine handling of digital television signals within the studios and distribution network. The view has been expressed elsewhere in this issue of *IBA Technical Review* that an increasingly important part of the transmission chain will be that of dedicated distribution satellites, already widely used in North America and the USSR, and currently planned for Eurovision. Hitherto, except for brief experimental purposes, television signals have been transmitted via satellites in analogue form. However, it is not too soon to consider the means whereby digit streams may be (a) processed and (b) modulated onto rf carriers for transmission to and from satellites. It will be appreciated that such basic techniques can be applied to the transmission of commercial telephony as well as that of television and sound programmes. Such systems could embrace existing earth-station/satellite configurations, or used with satellites operating via small earth stations, for community systems and potentially for direct broadcasting.

Digital Systems for Satellites

The use for space communications of single, limited capacity satellites in conjunction with many earth stations has resulted in the development of 'multiple-access' techniques. Two main techniques have emerged: frequency-division multiple-access (fdma) which is in current use; and time-division multiple-access (tdma) which is a strong contender for future truly digital systems.

The essential feature of fdma is that it divides the available satellite bandwidth into segments which are allocated exclusively to individual earth stations. Thus, earth station 'A' (see Fig. 1) transmits traffic in one (or more) band(s), and those other stations requiring to communicate with 'A' receive the transmissions in the appropriate 'down link' frequency band(s). An earth station may be able to accommodate all of its traffic on a single transmit carrier, but the 'return halves' of the transmission circuits are obtained by demodulating the several different received carriers from the appropriate earth stations.

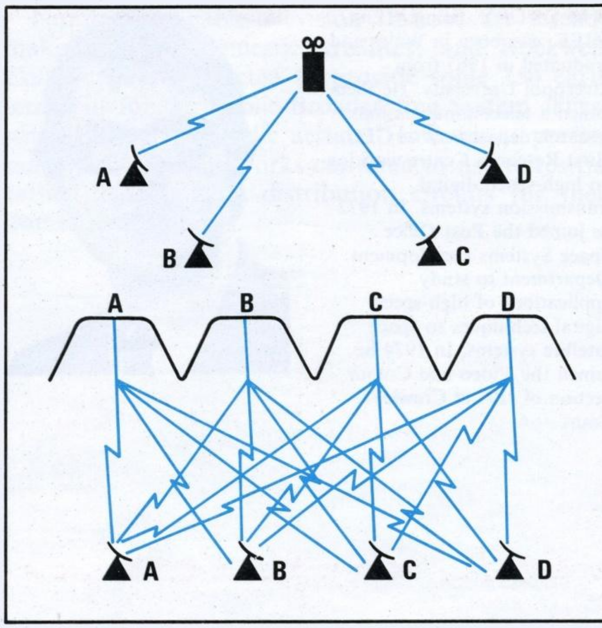
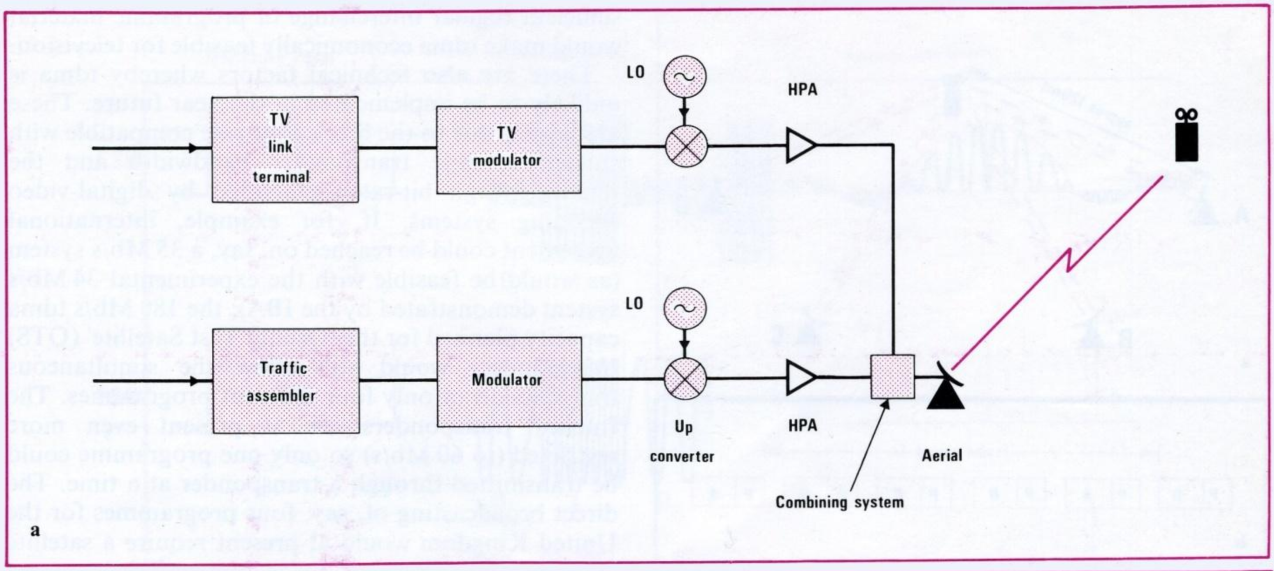


Fig. 1. A possible arrangement for frequency division multiple access (fdma). The essential feature of fdma is that it divides the available satellite bandwidth into segments allocated exclusively to individual earth stations. Thus, earth station 'A' may require to transmit to and receive from the segments allocated to stations 'B', 'C' and 'D'.

Thus, for fdma two-way telecommunications, a typical earth station configuration (Fig. 2) generally comprises one or two 'transmit chains' (one of which may be dedicated to television), at least one for each of those other earth stations from which transmissions are required. Digital modulation techniques can be applied to the fdma situation in two basic ways:

1 By occupying one or more complete satellite channel modules (transponders) with a single carrier which is continuously modulated by a high-speed digital signal. This could be derived by digitally multiplexing together several slower-speed signals.

2 By occupying one or more complete satellite channel modules with several carriers, each one continuously



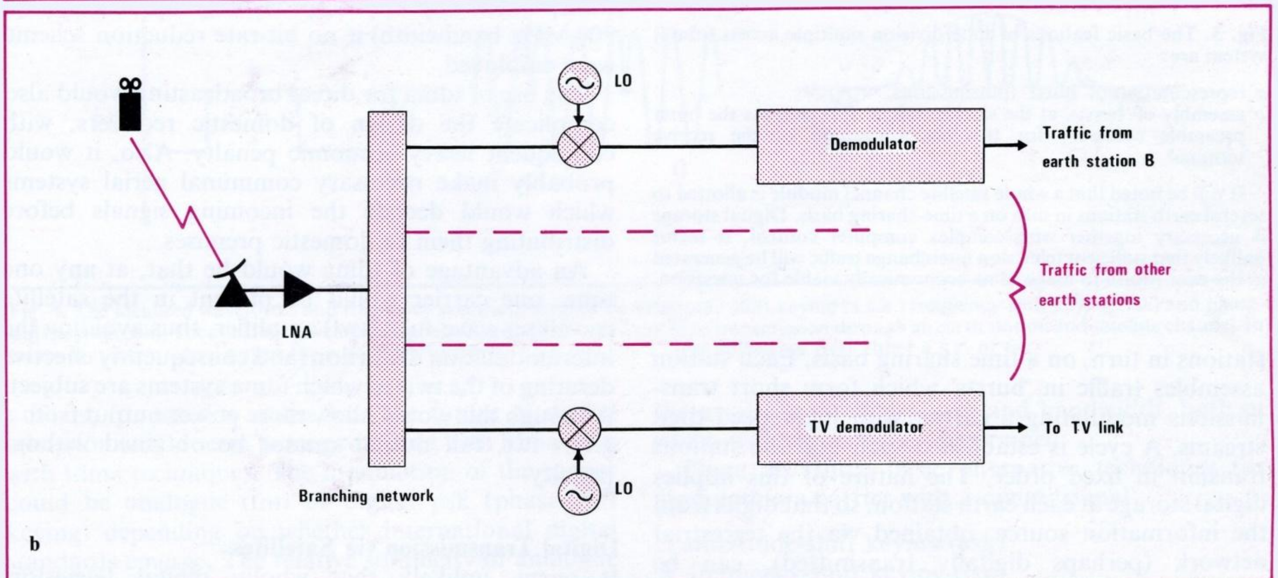


Fig. 2. Typical earth station configuration for fdma operation. (a) Transmit Chains; and (b) Receive Chains. Generally, an earth station may have one or two transmit chains, one of which can be dedicated to television, and many receive chains, at least one for each earth station the transmissions of which are to be received.

modulated by single (un-multiplexed) digit streams derived from different sources.

An example of (1) would be that of television with a bit-rate reduced to, say, 60 Mb/s. Such a signal could be modulated on to a single carrier with an occupied bandwidth of 40 MHz, i.e., approximately equal to that of the bandwidth of a typical current transponder. No multiplexing would be needed.

An example of (2) would be that of a system for telephony known as 'SPADE' (**S**ingle channel **P**er carrier, **A**ssignment by **D**emand **E**quipment). Essentially, each telephone circuit would be allocated a pair of carriers digitally modulated by the speech signals, so that each conversation would be self-contained.

The distinguishing feature of tdma is that an entire satellite channel module is allocated to several earth

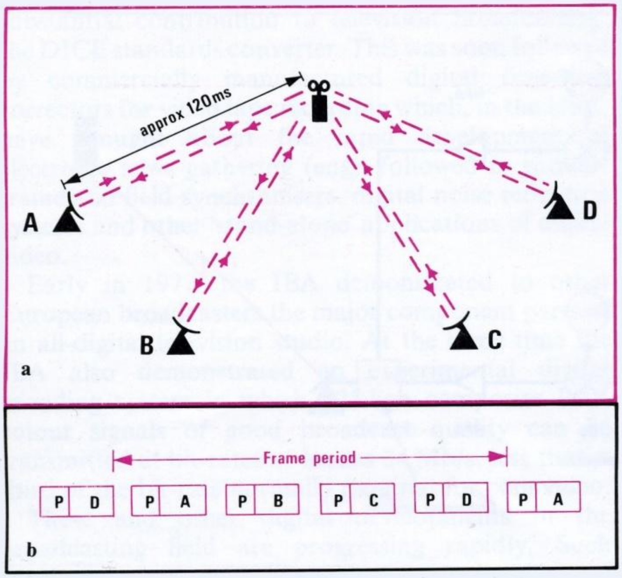


Fig. 3. The basic features of time division multiple access (tdma) system are:

a representation of 'burst' transmissions.
b assembly of 'bursts' at the satellite where *P* represents the burst preamble necessary for the synchronisation of the receive terminal.

It will be noted that a whole satellite channel module is allotted to several earth stations in turn on a time-sharing basis. Digital storage is necessary together with complex computer control. It seems unlikely that sufficient television interchange traffic will be generated in the near future to make tdma economically viable for television.

stations in turn, on a time sharing basis. Each station assembles traffic in 'bursts' which form short transmissions modulating a carrier with high-speed digit streams. A cycle is established such that the stations transmit in fixed order. The nature of this implies digital storage at each earth station, so that digits from the information source, obtained via the terrestrial network (perhaps digitally transmitted), can be absorbed at a constant rate and held in readiness for the high-speed burst transmission. The complex system is controlled by computer, so that the synchronisation of the burst transmission of station 'A' (see Fig. 3) can be set correctly and maintained with respect to that of the others.

The nature of television programme interchange via satellite is such that the demand would not require a system such as tdma. Programme interchange by satellite is still in the nature of a 'broadcast' type of operation, with a single programme being sent to 'multiple addresses' rather than 'unilateral' type exchanges. Therefore, it might be many years before sufficient regular interchange of programme material would make tdma economically feasible for television.

There are also technical factors whereby tdma is unlikely to be implemented in the near future. These are largely due to the limited bit-rate compatible with current satellite transponder bandwidth and the relatively high bit-rates generated by digital-video encoding systems. If, for example, international agreement could be reached on, say, a 35 Mb/s system (as would be feasible with the experimental 34 Mb/s system demonstrated by the IBA), the 180 Mb/s tdma capacity planned for the 'Orbital Test Satellite' (OTS) transponders would still allow the simultaneous transmission of only four different programmes. The Intelsat transponders are at present even more restricted (to 60 Mb/s) so only one programme could be transmitted through a transponder at a time. The direct broadcasting of, say, four programmes for the United Kingdom would at present require a satellite transponder capacity approaching 450 Mb/s (say, 300 MHz bandwidth) if no bit-rate reduction scheme were employed.

The use of tdma for direct broadcasting would also complicate the design of domestic receivers, with consequent heavy economic penalty. Also, it would probably make necessary communal aerial systems which would decode the incoming signals before distributing them to domestic premises.

An advantage of tdma would be that, at any one time, one carrier would be present in the satellite travelling-wave-tube (twt) amplifier, thus avoiding the intermodulation distortion (and consequently effective derating of the twt) to which fdma systems are subject. Although this would allow more power output from a given twt, full output cannot be obtained without penalty.

Digital Transmission via Satellites

It seems unlikely that wholly digital television transmission by satellite will be established at all widely in the near future. There are several important reasons for this:

a lack of internationally agreed standards for digital television;
b domination of satellite communications systems design by telephony;
c cost of designing satellites dedicated solely to broadcasting applications;
d difficulty of achieving economic operation of such a broadcast satellite in Europe, even if one were available.

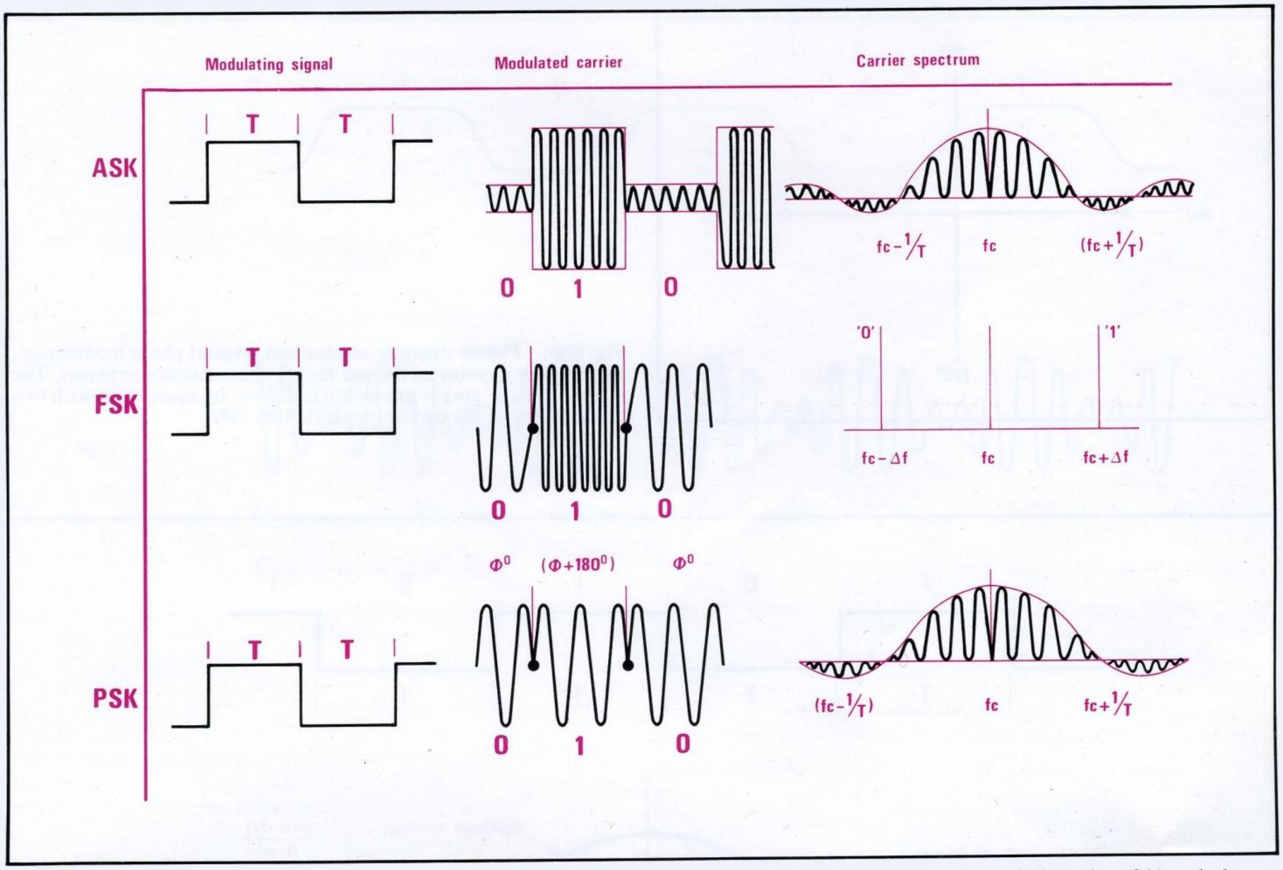


Fig. 4. The idealised waveforms and frequency spectra generated by amplitude-shift keying (a.s.k.) frequency-shift keying (fsk) and phase-shift keying (psk). The constant envelope rf signal of fsk and psk is well suited to transmission through an earth station and satellite channel. In terms of relative signal power for a given performance level psk has a clear advantage over either a.s.k. or fsk.

Thus, for satellite utilisation, the future of digital television would seem more promising with fdma than with tdma techniques. The modulation of the carrier could be analogue (fm) or digital psk (phase-shift keying) depending on whether international digital standards emerge. The relative simplicity of analogue modulation techniques would be advantageous for direct broadcasting to domestic receivers.

Digital Modulation

A detailed account of the fundamental techniques of digital transmission appeared in *IBA Technical Review Vol. 9*; but it will be useful here to review briefly the basic modulation systems.

The means whereby a digital baseband signal is applied to a radio frequency carrier is substantially independent of the information contained in the digit stream. The choice of modulation system, however, has a significant effect upon the efficient utilisation of the available satellite power and bandwidth, both of which will normally be constrained.

There are three basic alternative techniques for modulating a carrier with a digital signal:

i amplitude-shift keying (ask)
ii frequency-shift keying (fsk)
iii phase-shift keying (psk)

Idealised waveforms and frequency spectra of these three techniques are shown in Fig. 4. The figure contains also simple indications as to the means of selecting between these techniques.

Angle modulation is preferable to amplitude modulation because it permits transmission of a constant-envelope rf signal through the earth station and satellite channels, and offers other practical advantages. In the interest of power conservation, and technique based on suppressed carrier techniques would be preferable. These considerations tend to

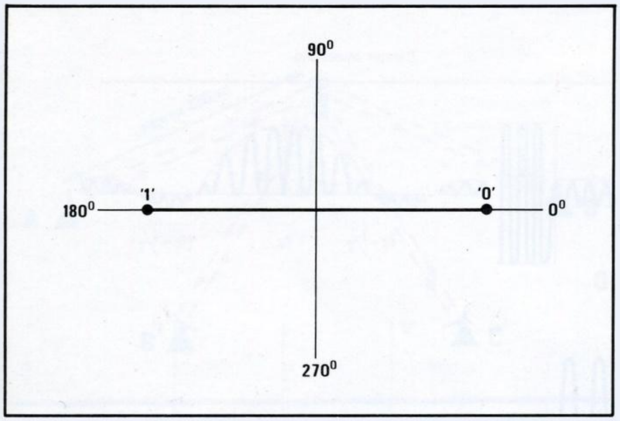


Fig. 5(a). Phasor diagram of idealised reversal phase modulation, the simplest member of the psk family of modulation schemes. The binary digits '1' and '0' are uniquely defined by association with two phase-states of the carrier, separated by 180°.

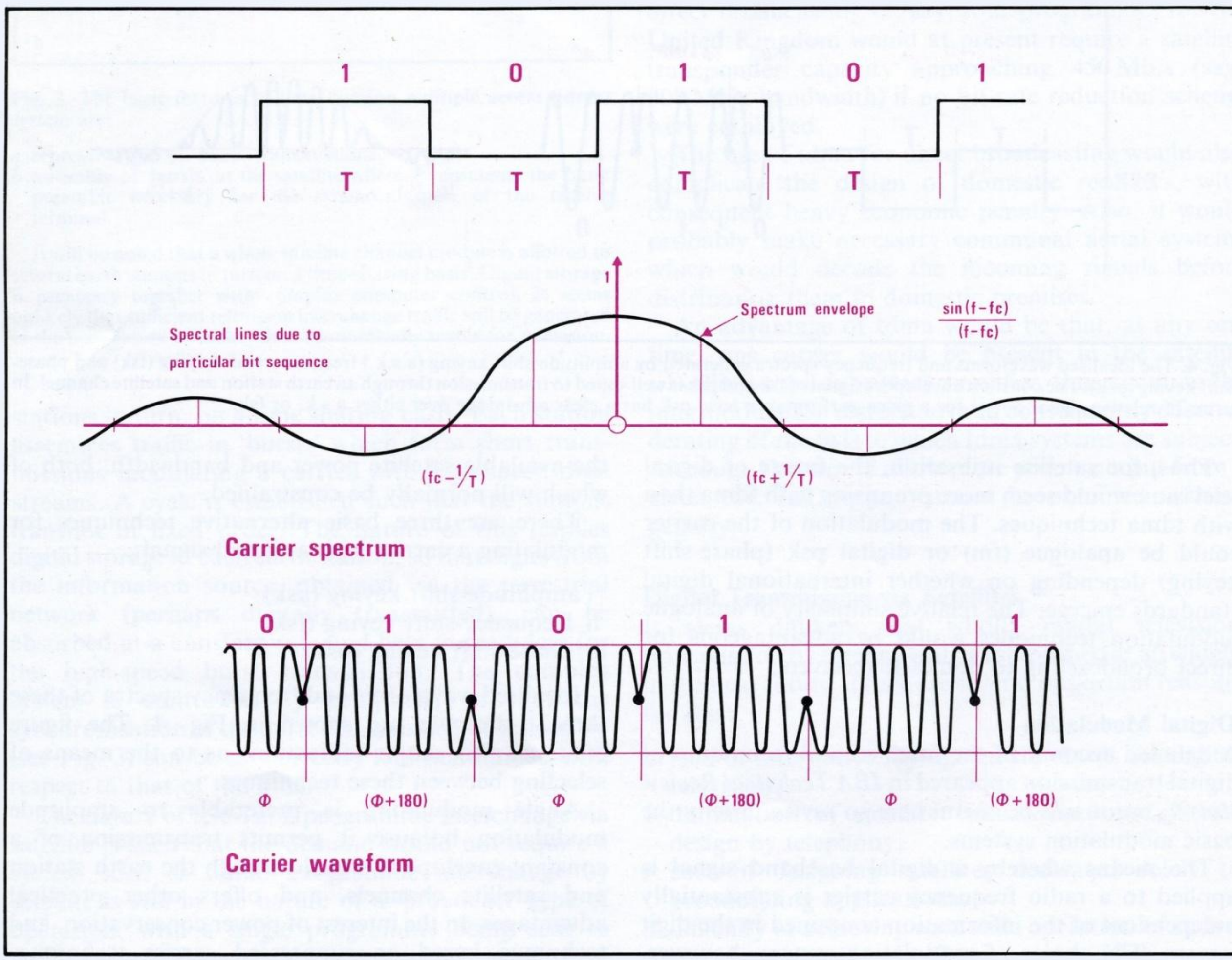


Fig. 5(b). The idealised waveform and spectra generated by a digit sequence with reversal phase modulation.

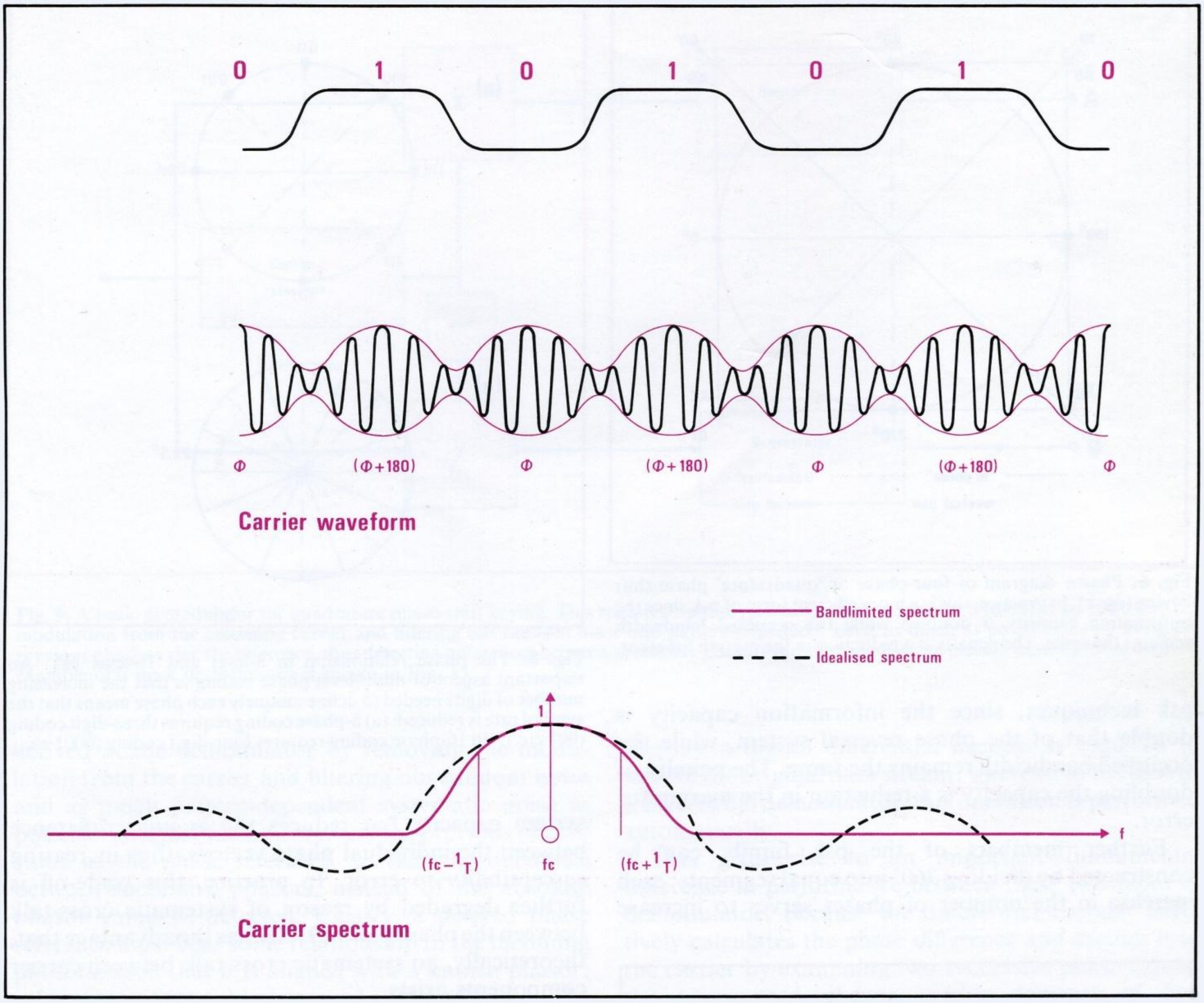


Fig. 5(c). Practical waveforms and spectra where band-limiting effect of the channel filtering spreads the phase transition in time, producing a 'pinch' or 'squeezing' effect in the carrier envelope.

favour phase-shift keying. Further, the frequency distribution of spectral energy does not favour frequency-shift keying. In terms of relative signal power (dB) for a given performance level, both a.s.k. and fsk require 3 dB more power than does psk, and this is undoubtedly the single most important factor determining the clear advantage of psk.

Phase shift-keying is, in fact, a whole family of modulation schemes, the simplest member of which is two-phase or reversal psk. In this case, the binary digits '1' and '0' are uniquely defined by association with two phase-states of the carrier, separated by 180° (see Fig. 5a). Idealised waveforms and spectra generated by a digit sequence are illustrated in Fig. 5b. Figure 5c shows practical waveforms and spectra, where the band-limiting effect of the channel filtering spreads the phase transition in time, producing a 'pinch' effect in the carrier envelope.

The next member of the psk family is four-phase psk, where the phase may be represented on a vector diagram as shown in Fig. 6. This is often referred to as quadrature phase-shift keying (qpsk) since it may be realised by adding the outputs of two reversal psk modulators the carrier phases of which are in quadrature (Fig. 7).

This technique is a more efficient means of utilising

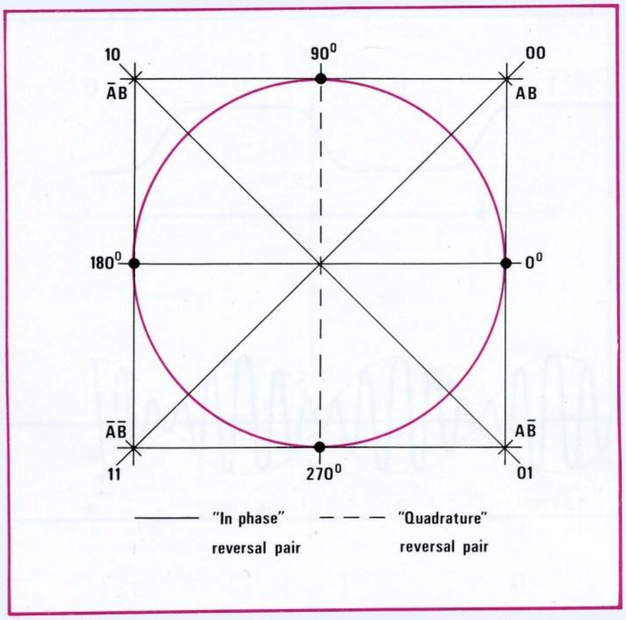


Fig. 6. Phasor diagram of four-phase or 'quadrature' phase-shift keying (qpsk). In practice, this is a more efficient form of psk since the information capacity is doubled while the occupied bandwidth remains the same. The penalty is a reduction in the margin for error.

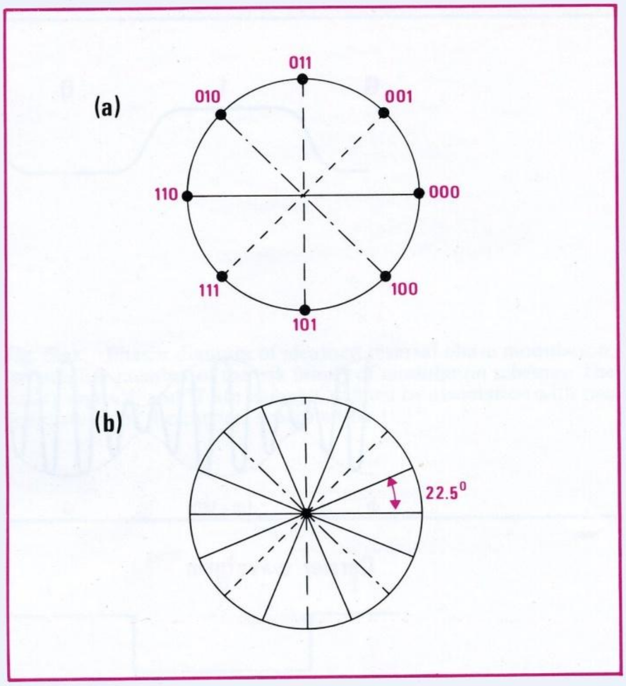


Fig. 8. The phase relationship in 8-level and 16-level psk. An important aspect of multi-level phase coding is that the increasing number of digits needed to define uniquely each phase means that the symbol rate is reduced: (a) 8-phase coding requires three-digit coding (001 etc.); (b) 16-phase coding requires four-digit coding (0001 etc.).

psk techniques, since the information capacity is double that of the phase reversal system, while the occupied bandwidth remains the same. The penalty of doubling the capacity is a reduction in the margin for error.

Further members of the psk family can be constructed by dividing 360° into equal segments: each increase in the number of phases serves to increase system capacity but reduces the angular difference between the individual phase vectors, thus increasing susceptibility to error. In practice, this trade-off is further degraded by reason of systematic cross-talk between the phase pairs. QPSK has the advantage that, theoretically, no systematic cross-talk between carrier components exists.

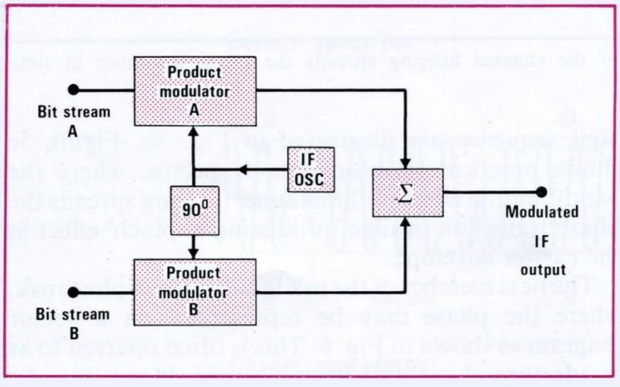


Fig. 7. Basic modulation for quadrature phase-shift keying. In effect, qpsk is realised by adding the outputs of two reversal psk product modulators, the carrier phases of which are in quadrature, by using a single i.f. oscillator and connecting a 90° phase-shift network in the feed to one modulator.

One of the important properties of multi-level phase coding is that the symbol rate is reduced. For example, for 16-phase psk, 4-bit binary numbers are required for defining uniquely each phase; this means that each phase symbol represents four binary symbols, thus reducing by a factor of four the repetition rate. This can be generalised to an n-fold reduction for a 2^n phase psk system.

The generally advantageous trade-off afforded by qpsk has brought about its acceptance as the standard form of psk technique.

QPSK Demodulation

A basic qpsk demodulator is shown in Fig. 9. It will be noted that a phase reference is required. This can be

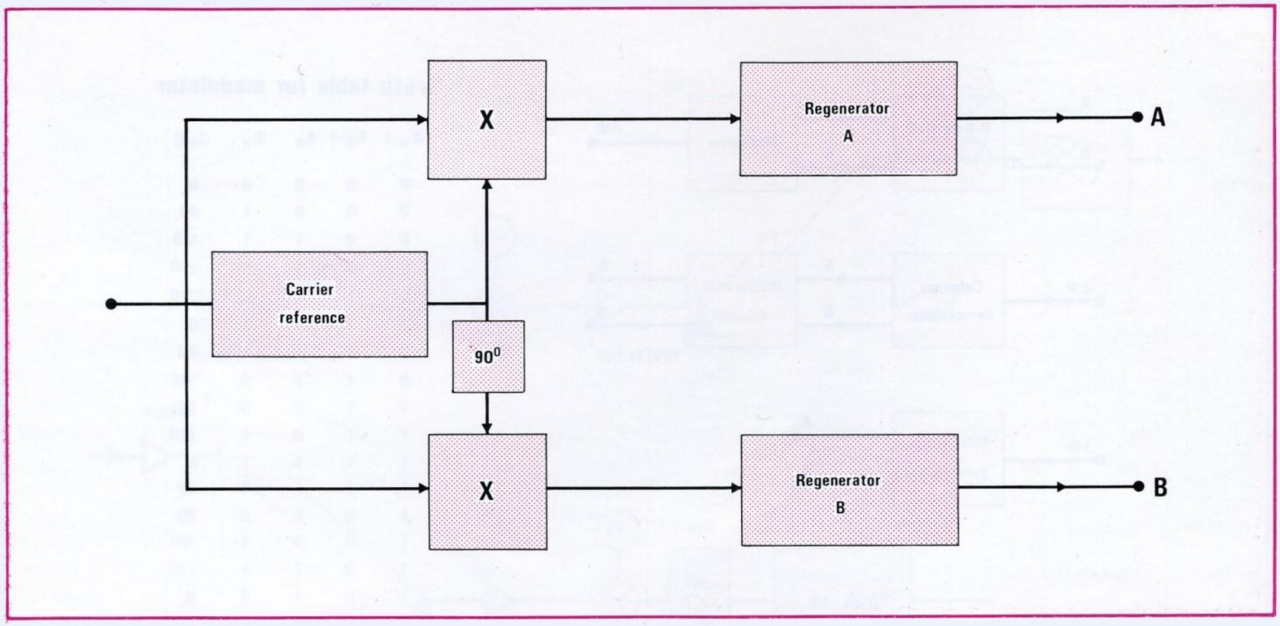


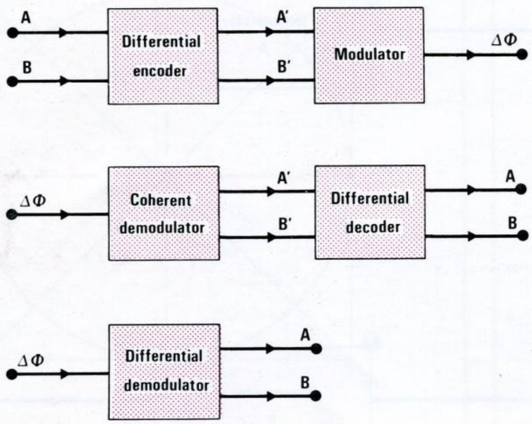
Fig. 9. A basic demodulator for quadrature phase-shift keying. This requires a phase reference which can be derived either by removing the modulation from the incoming carrier and filtering out random noise and pattern-dependent noise as much as possible, or by using the previous phasor value the reference, thus detecting differences between successive phasors rather than absolute phasor value. A more detailed example of a qpsk demodulator is shown in Fig. 13.

derived at the demodulator by removing the modulation from the carrier and filtering out random noise and as much pattern-dependent systematic noise as possible. Another method is to use the previous phasor value as the phase reference, so that the difference between successive phasors, instead of the absolute phasor value, is detected. Clearly, a derived phase reference must bear some relationship to the incoming phasors, such that it is aligned with a known phasor; otherwise, a four-fold phase ambiguity will exist. The differential method of demodulation suggests a practical means of resolving the ambiguity.

A system based on a recovered carrier, the phase of which is identical with that of the modulator phase reference (with a correction for transmission delay), is known as coherent psk; but, in practice, is unrealisable in this context. The binary digit pairs for qpsk can be uniquely allocated to the four possible absolute phases transmitted by the modulator, or can be digitally modified, or encoded, to cause transmission of binary digit-pair/phase-difference relationships. This facilitates demodulation by means of: (a) derived carrier reference (pseudo-coherent or differentially coherent); or (b) previous phasor (differential) references.

Note that, for the differentially coherent system (dcpsk), a digital differential decoder is required to restore the original data stream; whereas, in the case of a differential demodulator, this operation is performed automatically.

This gives rise to an important fundamental difference in performance between these two types of demodulator. Because the differential encoder effectively calculates the phase difference and applies it to the carrier by examining two successive phase values, the transmitted phasor carries elements of two successive binary digit pairs. At the demodulator, the coherent method (requiring a differential decoder) calculates the true binary data pairs by examining two successive (differentially encoded) received phasors. With the coherent detector, an error in one received phasor is not passed-on only to the corresponding output binary pair, but is also present in the binary calculation required to establish the subsequent binary data pair. Thus, an error extension process will occur which induces bit errors in pairs (or in fours if other, lower-order mechanisms are taken into account). These errors will not be detected by simple parity check error protection. This error extension ($\times 2$) is compensated for by adding an allowance to the carrier/noise ratio (cnr) such that the effective cnr for



Truth table for modulator

$A'_{n}-1$	$B'_{n}-1$	A_n	B_n	$\Delta_n\Phi$
0	0	0	0	0
0	0	0	1	90
0	0	1	1	180
0	0	1	0	270
0	1	0	0	270
0	1	0	1	0
0	1	1	1	90
0	1	1	0	180
1	1	0	0	180
1	1	0	1	270
1	1	1	1	0
1	1	1	0	90
1	0	0	0	90
1	0	0	1	180
1	0	1	1	270
1	0	1	0	0

Fig. 10. The practical problem of achieving a carrier reference of phase identical with that of the modulator reference—needed for coherent psk—has led to the use of 'differentially coherent' systems. For a dcpsk system a digital differential decoder is required for restoring the original data streams. This is performed automatically by means of a differential demodulator. There are fundamental performance differences between the coherent demodulator and the differential demodulator.

$2P_e$ is taken as the true cnr. This is effective overall but does not reflect the statistical nature of these error pairs. The allowance required is approximately 0·4 dB.

Differential demodulators do not cause error extension of this kind; so that, subjectively, a simple parity check error protection arrangement will be effective. Differential demodulation may result in single-bit errors, rather than error-pairs, but requires up to 3 dB extra cnr for restoring the P_e value. Whether this trade-off is acceptable depends upon circumstances: for example, where there are high cnr ratios in waveguide transmission systems, such a trade-off may well be worthwhile; but probably it would not be so in systems, such as radio relays or satellites, subject to fading. Satellite system designers would be more likely to employ dcpsk in an attempt to maximise utilisation of the available cnr ratio.

Modern Techniques

Figure 12 shows two basic methods whereby a carrier can be modulated with phase reversals.

The first system is a baseband-to-i.f. method, employing some form of balanced modulator, shown here as a conventional transformer-coupled diode-quad. This technique is suitable when an up-converter is to be used for translating the i.f. signal to the appropriate transmission frequency. The design of balanced modulators tends to limit the usable upper value of the i.f.

The second method is used primarily for direct modulation of the transmitted carrier and is based upon the use of delay lines to provide carrier phase-shifts. The digital baseband signals are then used to select the appropriate delay-line output for transmission. This technique is also found with systems using i.f. processing, provided that the frequency is sufficiently high to render practicable the use of delay lines. For example, a 90° phase-shift at 1 GHz represents 0·25 nanoseconds. A transmission line with a propagation velocity of, say, two-thirds the speed of light, would need to be about 20 cm long in order to provide a delay of 1 nanosecond. Frequencies below 1 GHz, however, can result in unwieldy delay lines; and, in such cases, the technique is usually avoided.

The demodulators associated with psk systems are more complex than modulators, although several of the elements may be common to both. For example, balanced modulators can be used as phase detectors.

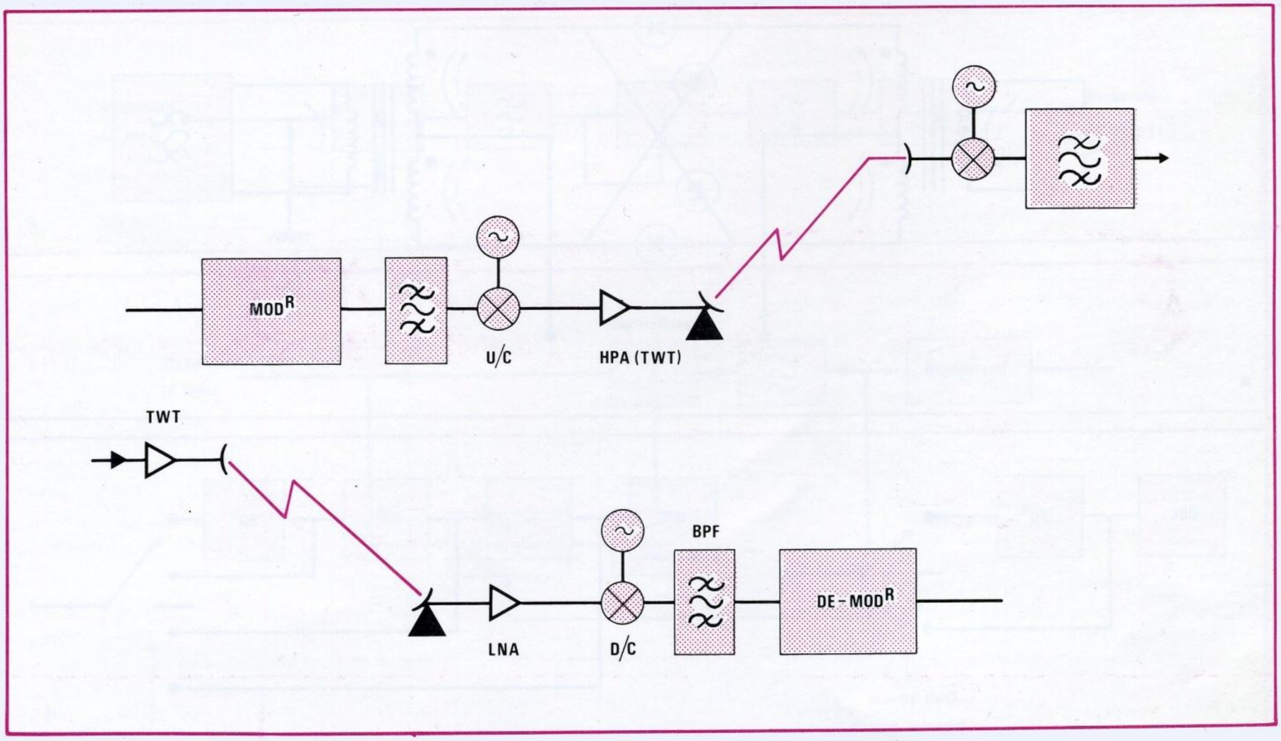


Fig. 11. A complete satellite link showing the elements which affect overall performance. With a digital link, imperfections in filters and travelling-wave tubes, etc., are reflected in an increase of the error-rate at the demodulator output. These imperfections can be allocated margins on the carrier/noise ratio required to restore the error rate to a given nominal value.

Figure 13 shows the configuration of dcpsk demodulators of a form likely to be used in satellite television systems.

The functions required are:

a detection of phase transitions and recovery of baseband modulation from the incoming stream of carrier bursts;

b regeneration of baseband modulation;

c differential decoding;

d coherent carrier recovery from each incoming carrier burst with sufficient response speed to permit correct demodulation of each one;

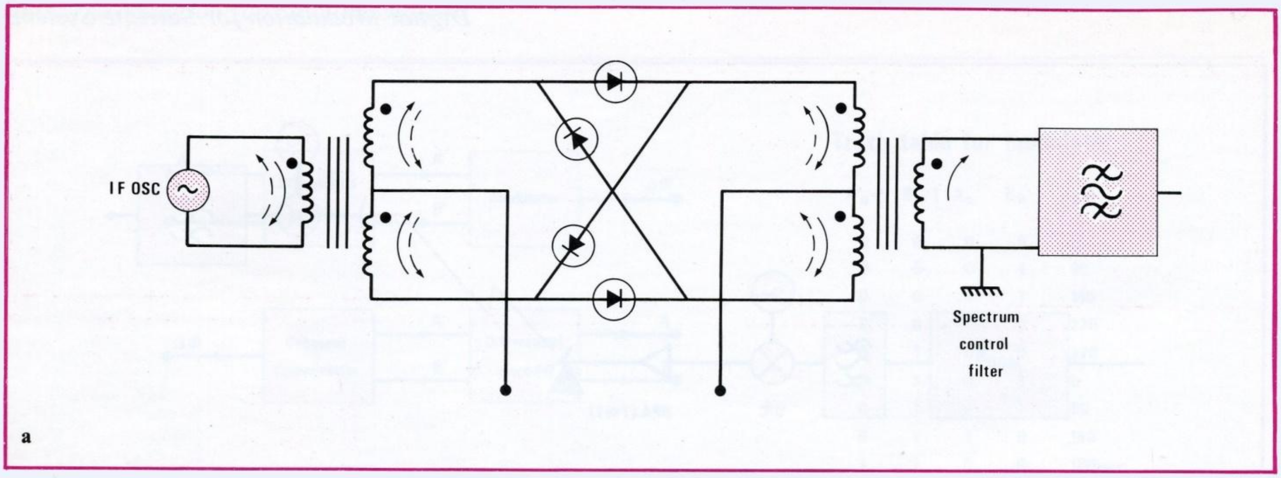
e clock recovery from each incoming carrier burst with sufficient response speed to enable correct regeneration of each one.

Items *b* and *c* are relatively simple logic operations and present no problems. The detectors *a* may be realised by means of balanced modulators, assuming that down-conversion is used to reduce the incoming carrier frequency to an acceptable i.f. The carrier and clock recovery sub-systems *d* and *e* need some consideration.

A clock recovery system can function directly from the input i.f. by the use of an envelope detector; this can be improved by means of a square-law form of detector which causes all 90° phase changes for qpsk to be added modulo-180° for reversals, giving a more active carrier envelope. Base-band recovery techniques could also be used.

The carrier recovery process can be performed in several ways; two of the more important techniques are: (1) the 'multiply/divide' technique; and (2) the Costas loop (or variants of this).

For the 'multiply/divide' approach a qpsk modulated carrier is passed through two square-law devices in tandem. These have the effect of adding the modulation phases modulo-90° and results in the removal of the modulation. Unfortunately in the process the carrier frequency is multiplied by a factor of four; if the i.f. is in the region of 1 GHz this leads to rather high frequencies being generated, so providing another constraint on the choice of i.f. The carrier is then processed to remove noise and as much pattern-dependent spurii as possible, before being frequency



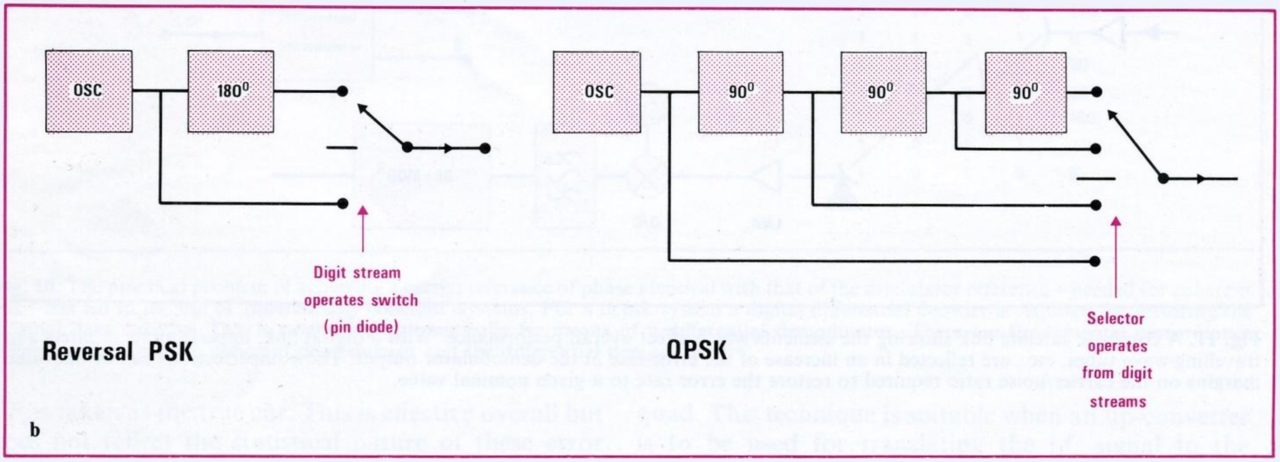


Fig. 12. Two basic methods of modulating a carrier with phase reversals: (a) the balanced (double balanced) modulator; (b) direct phase switching based on the use of delay lines to provide carrier phase-shifts.

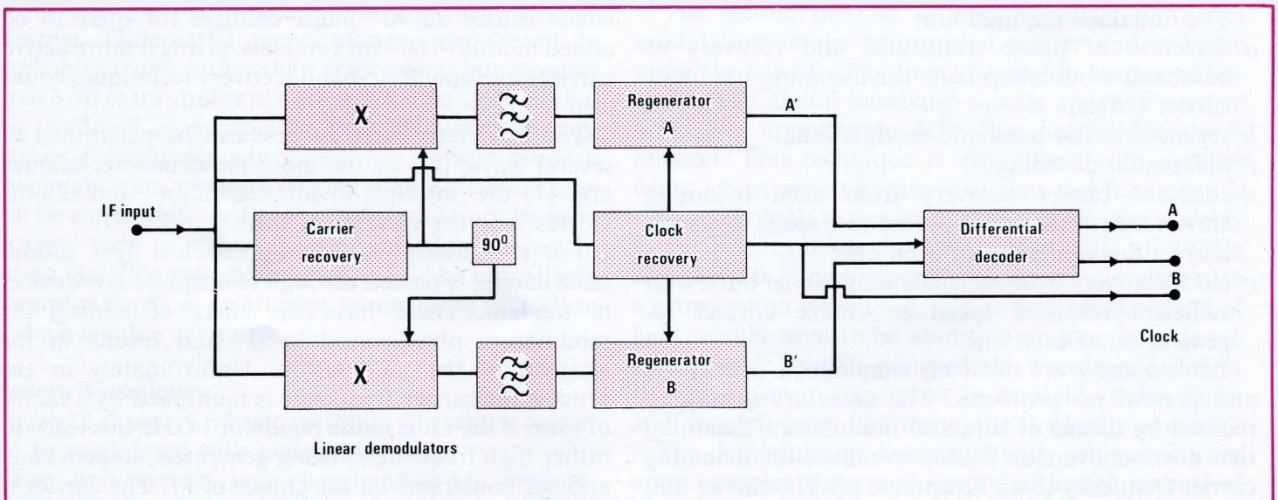


Fig. 13. The configuration of a complete dcpsk demodulator, of a form likely to be used in digital satellite television systems.

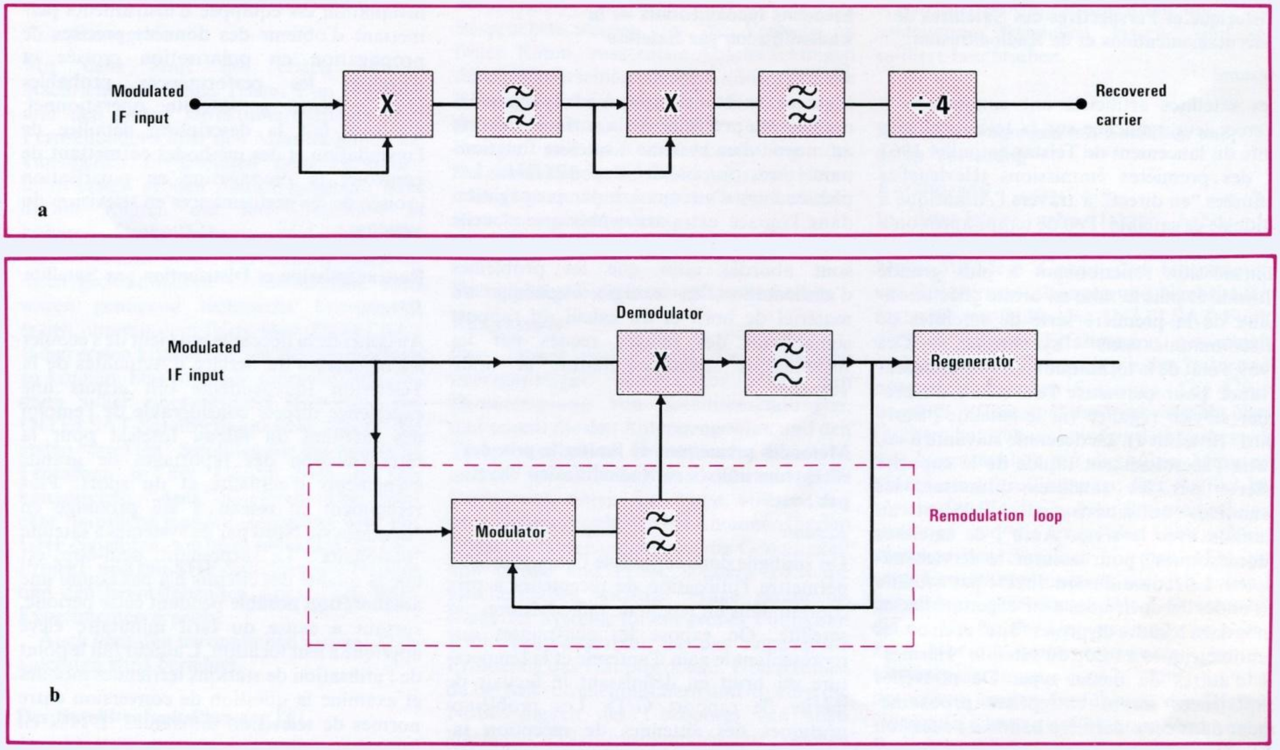


Fig. 14. Two basic carrier recovery techniques for qpsk systems; (a) the multiply/divide method of clock recovery in which the modulated carrier is passed through two square-law devices in tandem. However, this results in carrier frequency being multiplied by a factor of four, necessitating subsequent division by four to provide a clean carrier signal at the correct frequency; (b) the remodulator approach based on the Costas Loop. This uses a detached baseband signal to drive a modulator, the carrier input of which is the modulated carrier. If the local modulator operates out-of-phase with the modulation on the carrier, the remodulation process removes the modulation and delivers a clean carrier component. In practice, for qpsk, rather more complex versions are necessary.

divided by 4 to provide a clean carrier signal at the correct frequency. Phase-locked loops can be used in this processing: see Fig. 14.

Figure 14(b) shows an approach based on the Costas loop. This essentially uses the detected baseband signal to drive a modulator whose carrier input is the modulated carrier. If the local modulator operates out-of-phase with the modulation on the carrier, the remodulation process removes the modulation and delivers clean carrier component, which can be filtered before application to the phase detectors. The qpsk versions of this method is rather complex and may employ cross-coupling of the two baseband feedback signals, and it should be noted that the illustration shows the system as applied to reversal psk. If the carrier carries differentially encoded information no ambiguity of phase will arise in this loop.

Conclusions

There is clearly much more work to be done before a completely digital satellite transmission system can become available and devoted entirely to broadcasting applications. It would seem that the most promising techniques for experimental or early operational systems, probably sharing satellite capacity with telephony transmission, will be fdma, allied to either analogue (fm) or digital (psk) modulation of the carriers. It seems unlikely that a purely digital multiple access system (tdma), operating on a satellite with regenerative channels, will become available within many years, perhaps several decades.

The analogue versus digital debate is as strong in the satellite field as it is in those of television and radio broadcasting, but the levels of technology and high capital funding involved in satellite development mean progress is slower. There is hope that digital applications in broadcasting and in satellite systems may progress at a mutually acceptable pace, thus enabling convenient and efficient joint progress towards wider horizons in both these fields of engineering.

Historique et Perspectives des Satellites de Télécommunications et de Radiodiffusion.

Résumé

Les satellites artificiels ont commencer à exercer leur influence sur la télévision à la suite du lancement de Telstar en juillet 1962 et des premières émmissions télévisuelles diffusées “en direct” à travers l'Atlantique à l'aide de ce satellite. Peu de temps après on a vu l'apparition de satellites de re-transmission fonctionnant à plus grande altitude et puis la mise en orbite geostationnaire de la première série de satellites de télécommunications “synchrones”. Dès 1965, l'état de la technique était suffisamment avancé pour permettre l'ouverture du premier service régulier via le satellite “Early Bird” (Intelsat 1). La décennie suivante a vu, outre l'accroissement rapide de la capacité offerte par les satellites d'Intelsat, les premières utilisations, en URSS et au Canada avec la série “Anik”, de satellites “domestiques” pour assurer le service national. La radiodiffusion directe par satellite en ondes décimétriques a été expérimentée en Inde dans le cadre du projet “Site” et en ondes centimétriques à l'aide du satellite “Hermès” et d'autres du même type. De nouvelles expériences seront entreprises prochainement dans cette dernière bande à l'occasion du programme BSE japonais.

L'article contient aussi des indications sur l'OTS européen (satellite d'expérimentation en orbite).

Le Plan de l'UIT pour la Radiodiffusion par Satellite

Résumé

L'evolution de la radiodiffusion par satellite en Régions 1 et 3 au cours des 15 années à venir sera régie par un plan détaillé établi en 1977 à la Conférence Administrative Mondiale des Radiocommunications. L'article indique l'essentiel des principales dispositions du plan qui attribue au Royaume Uni cinq canaux depuis une position d'orbite située à 31° Ouest, laquelle position doit être partagée avec l'Irelande, l'Espagne, le Portugal et l'Islande. On explique la notion de “rapport de protection équivalent” et d'autres critères techniques servant à assurer une réception de bonne qualité, ce qui correspond à une marge de l'ordre de -31 dB vis-à-vis du brouillage venant d'un émetteur fonctionnant dans le même canal. Enfin, on expose les principales bases techniques de plan de l'UIT pour la Région I.

Eléments fondamentaux de la Radiodiffusion par Satellite

Résumé

L'auteur de cet article expose les principales données du problème de la surface couverte au moyen d'un système à satellite fonctionnant dans la bande des 12 GHz. Les phénomènes d'atténuation par propagation dans l'espace extra-atmosphérique et celle due aux précipitations dans l'atmosphère sont abordés ainsi que les problèmes d'alimentation en energie électrique du matériel de bord et du calcul du rapport signal/bruit des images reçues par les installations communautaires et individuelles.

Méthodes permettant de limiter le prix des récepteurs utilisés en Radiodiffusion directe par Satellite

Résumé

On souligne dans cet article l'importance de permettre l'utilisation de récepteurs à prix courant dans un réseau de radiodiffusion par satellite. On expose les contraintes que représentent le gain d'antenne et la température du bruit en définissant le facteur de mérite (le rapport G/T). Les problèmes pratiques des antennes de réception individuelles concernent non seulement la taille et la précision du profil mais aussi et tout autant le montage correct des appareils desservant le grand public. Le principal problème technologique de récepteur se pose au niveau des convertisseurs de modulation et du difficile passage des mélangeurs à hyperfréquence et des signaux issus d'appareils coûteux à haute performance à l'installation domestique courante. On expose successivement le principe d'un récepteur économique proposé par la NHK (Japon); les possibilités de réalisation de mélangeurs harmoniques à l'aide de diodes anti-parallèles et la question de filtrage à la réception. Enfin, si les ondes décimétriques ne seront probablement pas utilisées pour la radiodiffusion via satellite en Europe, ce ne sera pas nécessairement le cas dans d'autres régions. C'est pourquoi on présente, sur ce problème aussi, quelques réflections.

La Station Terrienne de l'IBA à Crawley Court

Résumé

L'IBA a construit, à son Centre Technique de Crawley Court près de Winchester, une installation pour la réception de signaux transmis par satellite dans la bande des 12 GHz; elle est dotée d'une antenne parabolique de 3 mètres de diamètre. Cette installation est équippée d'instruments permettant d'obtenir des données précises de propagation en polarisation croisée et d'évaluer les performances probables d'un système à satellite opérationnel. L'auteur fait la description détaillée de l'installation et des méthodes permettant de contrôler la propagation en polarisation croisée de les performances en télévision du système.

Re-transmission et Distribution par Satellite

Résumé

Au cours de la décennie qui vient de s'écouler les ingénieurs du Service d'Actualités de la Télévision Indépendente ont acquis une expérience directe considérable de l'emploi des satellites du réseau Intelsat pour la retransmission des reportages de grands evènements d'actualité et du sport. Plus récemment ce réseau a été prolongé en Amérique du Nord par les systèmes à satellite “nationaux”. Le surprenant, peut-être, est que la qualité des circuits n'a pas connu une amélioration notable pendant cette période, surtout à cause du tarif minutaire élevé appliqué à leur location. L'auteur fait le point de l'utilisation de stations terriennes mobiles et examine la question de conversion entre normes de télévision différentes. L'ITN en étant le premier organism de Télévision à employer le système DICE mis au point par l'IBA, a apporté une importante amélioration à la qualité des opérations de conversion, et ce avec remarquablement peu d'ennuis, s'agissant de la première mise en service à l'échelle grandeur de la vidéo numérique en radiodiffusion. Ce résultat a été facilité par l'utilisation d'appareils d'essai spécialement étudiés. On aborde aussi le problème de la compression de bande et les perspectives ouvertes aux systèmes de transmission numériques.

La Modulation Numérique au Service des Systèmes à Satellite

Résumé

Si la technologie des satellites de radiodiffusion a surtout fait appel à la modulation de fréquence en bande large, l'interêt que présente la modulation numérique est depuis longtemps reconnu. L'auteur énumère les différences entre accès multiple à partage de frëquence (fdma dans le texte) et accès multiple à partage dans le temps (tdma). Un examen critique des méthodes fondamentales de modulation numérique conduit à la conclusion que la modulation par déplacement de phase en quadrature (qpsk dans le texte) semble être la plus prometteuse. On en examine les problèmes pratiques de modulation et de démodulation.

Die Entwicklung der Fernmeldesatelliten

Kurzfassung

Mit dem Start des ersten aktiven Nachrichtensatelliten Telstar I im Juli 1962 und den ersten Direktübertragungen von Fernsehbildern über den Atlantik haben die künstlichen Erdsatelliten dem Fernsehen ihren ersten großen Anstoß gegeben. Bald darauf folgten die Relay-Satelliten in höheren Umlaufbahnen, und dann die Nachrichtensatelliten der Syncom-Serie in ihren geostationären Umlaufbahnen. 1965 waren genügend technische Fortschritte erzielt, um mit dem Early Bird (INTELSAT I) den ersten kommerziellen Betrieb eröffnen zu können. Das folgende Jahrzehnt brachte dann außer einer rapiden Steigerung der INTELSAT-Satellitenkapazität auch die ersten "direkten" Satelliten für das häusliche Fernsehen in der UdSSR und in den kanadischen "Anik"-Satelliten. Der "direkte" häusliche Rundfunkempfang wird mit UHF-Satelliten, wie beim indischen "SITE"-Projekt, und mit SHF-Satelliten wie Hermes und den bevorstehenden japanischen BSE-Experimenten erprobt.

Auch über den europäischen Orbital Test-Satelliten wird berichtet.

Der Satellitenfunk-Plan der ITU

Kurzfassung

Die Entwicklung des Satellitenfunks in den Regionen 1 und 3 wird sich in den nächsten 15 Jahren aufgrund eines 1977 von der World Administrative Radio Conference entworfenen Planes vollziehen. Der Artikel gibt einen Überblick über die Hauptempfehlungen dieses ITU-Planes, nach dem für Großbritannien in einer Position von 31°W (dieselbe wie für die irische Republik, Spanien, Portugal und Island) 5 Programmkanäle zur Verfügung stehen sollen. Ferner werden das Äquivalentschutzverhältnis und andere technische Kriterien erläutert, durch die erstklassige Übertragungen mit einem Gleichkanalstörungsfaktor von nur rund -31 dB sichergestellt werden sollen. Auch die Einzelheiten der technischen Kriterien, die die wesentlichen Grundlagen dieses ITU-Planes bilden, werden erläutert.

Die Grundlagen des Sendens mit Satelliten

Kurzfassung

Der Artikel behandelt die grundlegenden Faktoren, die die Abdeckung von Versorgungsbereichen mit einem mit 12 GHz arbeitenden Satellitensystem bestimmen. Besprochen werden u.a. die Verluste im freien Raum, zusätzliche Abschwächungen durch Niederschläge in der Atmosphäre, die Versorgung der Anlagen und Einrichtungen der Satelliten mit der nötigen elektrischen Energie und die zur Ermittlung des Rauschabstandes bei Bildern für den Heim- oder Gemeinschaftsempfang erforderlichen Berechnungsmethoden.

Preisgünstige Satellitenempfangstechniken

Kurzfassung

Der Artikel unterstreicht die Bedeutung preisgünstiger Empfänger für den Direktempfang von Satellitensendungen, und nimmt die den Antennengewinn und den Temperaturbeiwert begrenzenden Faktoren und die Spezifizierung einer Gütezahl (G/T-Verhältnis) unter die Lupe. Unter den praktischen Problemen bei Antennen für den Heimempfang ist nicht nur die Genauigkeit von Größe und Profil, sondern auch die gleichermaßen wichtige Frage genau installierter Systeme für ein großes Publikum. Beim Empfängerbau ist das sogenannte Frontende das Hauptproblem. Und dann ist da bei Mikrowellenmischern und -quellen die Notwendigkeit des Übergangs von kostspieligen Präzisionsbauteilen zu solchen für den "Hausgebrauch". Eine von NHK Japan vorgeschlagene preisgünstige Konstruktion wird beschrieben; die Möglichkeit der Verwendung harmonischer Mischer mit Hilfe antiparalleler Dioden erörtert; und die Frage von Empfangsfiltern besprochen. Obwohl UHF-Sendungen von Satelliten für den europäischen Bereich unwahrscheinlich sind, mag dies für andere Teile der Welt nicht der Fall sein. Eine Frage, die ebenfalls gestreift wird.

Die Empfangsstation der IBA in Crawley Court

Kurzfassung

Die IBA hat in ihrem technischen Zentrum in Crawley Court bei Winchester ein experimentelles Satellitenempfangssystem (12 GHz) mit einer 3 m großen Parabolantenne gebaut, das speziell dazu ausgerüstet ist, den IBA-Ingenieuren genaue Ausbreitungsdaten über die Kreuzpolarisierungseffekte zu liefern, und sie in die Lage versetzen soll, die von einem einsatzfähigen Satellitensystem zu erwartende Leistung festzustellen. Das Empfangssystem selbst und der Weg, wie sich Kreuzpolarisierungsausbreitung und Fernsehleistung feststellen lassen, sind detailliert beschrieben.

Relaisübertragungen mit Satelliten und deren Verteilung

Kurzfassung

In den letzen zehn Jahren haben die Ingenieure von Independent Television News auf dem Gebiet der Übertragung von Sportveranstaltungen und Nachrichtenmaterial mit Hilfe des INTELSAT-Funkdienstes genaue Erfahrungen gesammelt, und in jüngerer Zeit auch mit den "internen" nordamerikanischen Systemen. Die Übertragungsqualität, und das wird vielleicht überraschen, hat sich nicht wesentlich verbessert; was hauptsächlich auf die hohen Minutenkosten zurückzuführen ist. Der Artikel bespricht den Einsatz mobiler Bodenempfangsstationen und die Frage der Umwandlung zwischen den einzelnen Normen. ITN, die erste Fernsehorganisation, die sich des von der IBA ausgearbeiteten DICE-Systems bediente, hat bei der Umwandlung von Norm zu Norm bemerkenswerte Qualitätsverbesserungen erzielt, und ist bei der ersten großen Einführung der Digitalvideoaufzeichnung auf überraschend wenige Betriebsprobleme gestoßen. Dabei hat die Verwendung einer speziell entworfenen Prüfausrüstung mitgeholfen. Auch über die Bandbreitenverengung und die Aussichten für Digitalübertragungssysteme wird in diesem Zusammenhang einiges gesagt.

Digitalmodulation für Satellitensysteme

Kurzfassung

Die Satellitentechnik hat sich zwar in erster Linie auf der Basis der Breitbandfrequenzmodulation entwickelt, aber schon seit längerem werden auch die Vorteile der Digitalmodulation anerkannt. Der Artikel behandelt die Unterschiede zwischen dem Frequenzmultiplexzugriff (frequency division multiple access = fdma) und dem Zeitmultiplexzugriff (time division multiple access = tdma). Die Erörterung der grundlegenden Digitalmodulationssysteme führt zu dem Schluß, daß die Phasenquadraturumtastung (quadrature phase-shift keying = qpsk) das vielversprechendste System ist, und auf dieser Basis werden die praktischen Probleme der der qpsk-Modulation und -Demodulation beschrieben.

Historia y perspectivas de los satélites de telecomunicación y radiodifusión

Resumen

Los satélites artificiales comenzaron a ejercer su influencia en la televisión tras el lanzamiento del Telstar en julio de 1.962 y después de las primeras emisiones televisivas transmitidas "en directo" a través del Atlántico con la ayuda de este satélite. Poco tiempo después llegaron los satélites de retransmisión a mayor altura y, más tarde, se puso en órbita geostacionaria la primera serie de satélites de telecomunicaciones "sincrónicas". Para 1.965, la tecnologia había avanzado suficiente como para permitir el establecimiento del primer servicio regular vía el satélite "Early Bird" (Intelsat I). Durante el decenio siguiente, aparte de verse un rápido aumento en la capacidad ofrecida por los satélites de Intelsat, se utilizaron por vez primera, en la URSS y en el Canadá con la serie "Anik", los satélites domésticos que aseguran el servicio nacional. La radiodifusion directa por satélite en ondas decimétricas ha sido experimentada en el proyecto hindú "SITE" y también en ondas centimétricas en tales satélites como el "Hermes" y en el próximo programa experimental japonés "BSE".

El artículo también dedica cierto espacio al tema del satélite europeo experimental en órbita.

El plan de la UIT para la radiodifusión por satélite

Resumen

La evolución de la radiodifusión por satélite en las Regiones 1 y 3 durante los próximos 15 años dependerá de un plan detallado elaborado en 1.977 en la Conferencia Administrativa Mundial de Radiocomunicaciones. En el articulo se exponen, de una forma general, las principales recomendaciones de este plan de la UIT, en el que se asignan al Reino Unido cinco canales desde una posición orbital situada a 31° oeste. Esta posición debe ser compartida con Irlanda, España, Portugal e Islandia. Explica la idea de la "relación de protección equivalente" y otros aspectos técnicos que sirven para garantizar una recepción de calidad correspondiente a un margen del orden de -31 dB frente a la interferencia procedente de un emisor que funcione en el mismo canal. También expone el criterio técnico en el que se basa el Plan de la UIT para la Región 1.

Principios fundamentales de la radiodifusión por satélite

Resumen

En el artículo se analizan los factores básicos relacionados con la zona servida por medio de un sistema de satélite que funcione en la banda 12 GHz. Se detallan los fenómenos debidos a la atenuación de la propagación en el espacio extra-atmosférico y a la atenuación originada por la lluvia o precipitaciones en la atmósfera, así como los problemas relativos a la producción de suficiente energía eléctrica para el equipo instalado en el satélite y al cálculo de la relación señal/ruido para las imágenes recibidas por las instalaciones comunitarias e individuales.

Métodos para reducir el costo de los receptores utilizados en la radiodifusión directa por satélite

Resumen

En este artículo se hace hincapié sobre la importancia de producir receptores de bajo costo para el sistema de radiodifusión directa por satélite. Señala las limitaciones que suponen la ganancia en la antena y la temperatura de ruido, y la especificación del factor de la calidad (la relación G/T). Los problemas prácticos relacionados con las antenas receptoras de los hogares no sólo se refieren al tamaño y a la precisión del perfil, sino también al igualmente importante aspecto relativo a la instalación exacta de equipo apropiado para grandes públicos. El conjunto de mezclador y oscilador, así como el proceso evolutivo para que los sistemas y mezcladores de microondas, basados en componentes de precisión de elevado precio, pasen a formar parte de las instalaciones domésticas corrientes representan las mayores dificultades en el proyecto de los receptores. El artículo trata también de los temas siguientes: una reseña de un diseño económico propuesto por la NHK (Japón); la posibilidad de utilizar mezcladores armónicos auxiliados por diodos antiparelelos; y un análisis de los filtros de recepción. Aunque no es probable que las ondas decimétricas se utilicien en la radiodifusión por satélite en Europa, ello quizás no pueda afirmarse con respecto a otras regiones. Por consiguiente, también se han incluido algunos comentarios sobre este aspecto.

La estación terrestre de la IBA en Crawley Court

Resumen

La IBA ha construido, en su centro técnico de Crawley Court, cerca de Winchester, una instalación para la recepción de las señales transmitidas por satélite en la banda de 12 GHz. Esta instalación, que está dotada de una antena parabólica de 3 metros de diámetro, tiene equipo especial para facilitar información detallada con respecto a los efectos de la polarización cruzada y para permitir determinar el rendimiento probable de un servicio por satélite. El artículo describe detalladamente la instalación y los métodos que permiten controlar la propagación por polarización cruzada y el rendimiento del sistema de televisión.

Retransmisión y distribución por satélite

Resumen

Durante el último decenio, los técnicos del Servicio Independiente de Teledocumentales de Actualidad (ITN según sus siglas inglesas) adquirieron una gran experiencia en la utilización del sistema de satélites Intelsat para la retransmisión de importantes acontecimientos de actualidad y pruebas deportivas. Recientemente, el sistema se amplió en Norteamérica a los satélites "nacionales". Quizás resulte sorprendente que la calidad de los circuitos no haya mejorado considerablemente, pero esto se debe principalmente a su elevado costo por minuto. En el artículo se hace una reseña sobre la utilización de estaciones terrestres móviles y se examina el tema referente a la normalización de las práticas televisivas. ITN, siendo el primer organismo de la televisión que utilizó el sistema DICE proyectado por la IBA, ha proporcionado una importante aportación en lo que respecta a la calidad de la conversión de dichas normas, habiendo tenido un número extraordinariamente pequeño de problemas functionales en la primera importante introducción método video-numérico en las emisiones de televisión. Esta labor se ha visto facilitada por la utilización de equipo experimental de diseño especial. También se reseña el problema relacionado con la compresión de la anchura de banda y las perspectivas abiertas a los sistemas numéricos de transmisión.

Modulación numérica para sistemas de satélites

Resumen

Aunque la tecnología de los satélites de radiodifusión se ha ideado principalmente teniendo como base la modulación de frecuencia de banda ancha, las ventajas de la modulación numérica se han reconocido desde hace tiempo. En el artículo se examinan las diferencias existentes entre el acceso múltiple de división de frecuencias (fdma según sus siglas inglesas) y acceso múltiple de división de tiempo ("tdma"). Al analizar los métodos fundamentales de modulación numérica se llegó a la conclusión de que la modulación por defasaje de cuadratura (qpsk) era el método más prometedor. También se describen los problemas prácticos relacionados con la modulación y demodulación "qpsk".

IBA TECHNICAL REVIEW

1 **Measurement and Control***

2 **Technical Reference Book, edition 3**

3 **Digital Television***

4 **Television Transmitting Stations***

5 **Independent Local Radio***

6 **Transmitter Operation and Maintenance**

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